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BUTTERWORTHS SCIENTIFIC PUBLICATIONS

Maize in Tropical African Agriculture

MARVIN P. MIRACLE
Food Research Institute, Stanford University, California, U.S.A.

It is widely held that agriculture offers, in most instances, the greatest possibilities for increasing productivity in the early stages of economic development (NURKSE, 1953; LEWIS, 1955; BUCHANAN and ELLIS, 1955); that agricultural productivity must rise for economic growth to be achieved and maintained is undisputed. For most areas of the world, however, we know painfully little, as yet, about which avenues of agricultural investment give the greatest increment.

Prominent among the questions that arise when one begins to search for methods of increasing the productivity of tropical agriculture, particularly in Africa, are: (*1*) What are the most productive foods? (*2*) Which crop or combination of crops gives the highest caloric yield in any particular region or locality? To assume that the most advantageous crop is the one already established, while often reasonable, can lead one far from the truth; agricultural systems are moulded by historical, social, and cultural influences as well as by those that are economic. Without knowing the cardinal characteristics of the crops grown and the reasons for the existing cropping pattern, the need for change cannot be detected nor its implementation rationally planned. Highly pertinent to economic development, then, is the question of what yields are characteristic of the crops and crop complexes now grown.

Of equal, or perhaps greater, importance is the question of what increases in output and/or reductions in costs of production of different crops can be achieved by increased capital investment in such forms as improved seed, fertilizers, pesticides, or mechanization. It is also important to know the cost and feasibility of storing various food commodities and of moving them over long distances to supply present or future urban populations. Another important consideration must be changes in the African's attitude toward each of the various foods with rising levels of living.

The pages that follow are a preliminary report on one major African commodity—maize—and focus on what is known, of a general nature, about how it is produced, stored, marketed, and consumed in Africa. A study in progress will examine the competitive position of maize *vis-à-vis* the other major food crops and its potential role within the larger, more productive agricultural economies requisite to economic growth in tropical Africa*.

PRODUCTION

Maize is a popular African food. In the form of roasting ears (corn-on-the-cob), a favourite vegetable wherever maize can be grown, it is eaten by most African peoples (although other forms of maize consumption are larger in total). In fact, no other starchy staple is so widely grown in tropical

* Tropical Africa is herein defined as sub-Saharan Africa exluding the Union of South Africa, Basutoland, Swaziland, Bechuanaland, and Southwest Africa; it includes Madagascar.

Africa, and, if the data are reasonably reliable, only the millets and sorghums and manioc (cassava) bulk larger, in aggregate, as contributors of calories (*Figure 1*).

Despite the large margin of error which characterizes African crop statistics, it is certain that in much of East and South-Central Africa maize is the dominant staple, and often ranks as the second crop where it is not dominant. Elsewhere it is dominant only in three rather small zones (the Bamenda Highlands of the British Cameroons, lower Dahomey, and lower Togoland), and is typically of secondary or lesser importance.

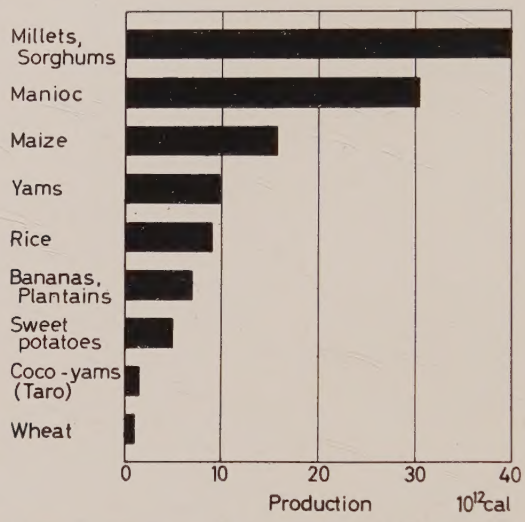

Figure 1. Production of the major tropical African starchy staples, about 1950 (data from Table 1)

It is a little surprising that maize is not more important. Climatic differences are not large enough to explain completely the sharp contrast one finds in the position of maize within tropical Africa, or between the humid tropics of Africa and Central America. In tropical Mexico, particularly, maize is practically the only starchy staple and nothing competes successfully with it, save wheat in the urban areas; on the other hand, in West Africa, maize takes its place with, and usually behind, manioc, yams, bananas and plantains, millets and sorghums, and rice (*Table 1*).

GEOGRAPHICAL DISTRIBUTION OF MAIZE IN TROPICAL AFRICA ABOUT 1950

Breaking the vast area we have called tropical Africa into something like thirds—the three broad divisions that are commonly used, viz. West, Central, and East Africa—one finds that production data, even when discounted for a considerable margin of error, bear out the general impression one gets from the literature; maize production is larger in total and relative to that of other starchy staples in East than in West or Central Africa (*Table 1*).

These three areas are here defined as follows. The French Cameroons and all countries west are called West Africa; French Equatorial Africa, the

*Table 1. Production of the major tropical African starchy staples, about 1950**

Crop	Thousand metric tons			Thousand million calories			Per cent of total[a]		
	West Africa	Central Africa	East Africa	West Africa	Central Africa	East Africa	West Africa	Central Africa	East Africa
Roots, tubers	*27,734*	*9,738*	*8,945*	*27,787*	*10,476*	*8,784*	*46*	*43*	*25*
Manioc[b]	14,896	8,728	4,525	16,237	9,513	4,932	28	39	13
Yams[c]	10,584	221	156	9,526	199	140	16	1	—
Sweet potatoes[d]	784	774	4,187	760	751	4,061	1	3	11
Coco-yams[e]	1,470	15	77	1,264	13	66	2	—	—
Cereals	*8,539*	*3,432*	*6,893*	*29,847*	*12,044*	*24,167*	*51*	*48*	*66*
Millets, sorghums[f]	5,880	2,001	3,742	20,286	6,904	12,911	34	28	35
Maize[g]	1,356	1,100	1,962	4,882	3,960	7,063	8	16	20
Rice[h]	1,303	306	887	4,679	1,097	3,184	8	5	9
Wheat[i]	—	25	302	—	81	954	—	—	3
Bananas, plantains[j]	*2,352*	*2,556*	*4,419*	*1,764*	*1,917*	*3,314*	*3*	*8*	*9*
Total	38,625	15,726	20,257	59,398	24,437	36,680	100	100	100

* Data in thousand metric tons from, or derived from, sources listed in Appendix to *Figure 2*. For definition of West, Central and East Africa, see p 2–4. Yam and coco-yam production totals have been adjusted to a 'net' basis by deducting one third for seed requirements. No adjustment has been made for seed with the other crops; for manioc, sweet potatoes, and bananas and plantains no production need be saved for seed; for the cereals the range is probably from 2·5 per cent for maize to 10 per cent for millets and sorghums, which is likely to be less than the margin of error in the basic data. For West Africa, except for maize, production was estimated from area and the following average yield estimates, both provided by B. F. Johnston of the Food Research Institute (in quintals per hectare): manioc, 80; yams, 60; sweet potatoes, 40; coco-yams, 30; millets and sorghums, 6; rice, 7; bananas and plantains, 80. For Uganda, also, average yields (taken as 80 quintals per hectare) were applied to acreage for manioc and bananas and plantains. For Angola and Kenya, where yams and sweet potatoes were given together, the following division was made: Angola, crops assumed to be of equal magnitude; Kenya, sweet potatoes assumed to be twice as important as yams. For Tanganyika, where banana production was given in bunches for some districts, a bunch of bananas was assumed to weigh 30 pounds. No conversion factor was given in Tanganyika sources, but factors used by the FAO range from 21 to 72 pounds and are considered 'only approximate' because bananas are 'extremely variable' (FAO, 1954). Per cent of crops listed and thousand million calories are the author's computations. The following caloric factors per 100 grammes 'as purchased' (from CHATFIELD, 1954) were used: manioc, 109; yams, 90; sweet potatoes, 97; coco-yams, 86; millets and sorghums, 345; maize, 360; rice, 359; wheat, 334; bananas and plantains, 75.

[a] Per cent of crops listed (based on calories produced). [b] *Manihot utilissima.* [c] *Dioscorea spp.* [d] *Ipomoea batatas.* [e] *Colocasia spp.* and *Xanthosoma sagittifolium.* [f] Principally *Sorghum vulgare, Pennisetum,* and *Eleusine coracana.* [g] *Zea mays.* [h] *Oryza sativa* and *Oryza glaberrima.* [i] *Triticum vulgare.* [j] Principally *Musa sapientum* and *Musa paradisiaca.*

Sudan, the Belgian Congo, Angola, and the Rhodesias form Central Africa; the remainder, roughly tropical Africa east of 30° east longitude is East Africa. The Sudan and the Rhodesias, all lying on 30° east longitude, are counted as Central Africa, whereas Ruanda–Urundi, similarly bisected, is considered East Africa.

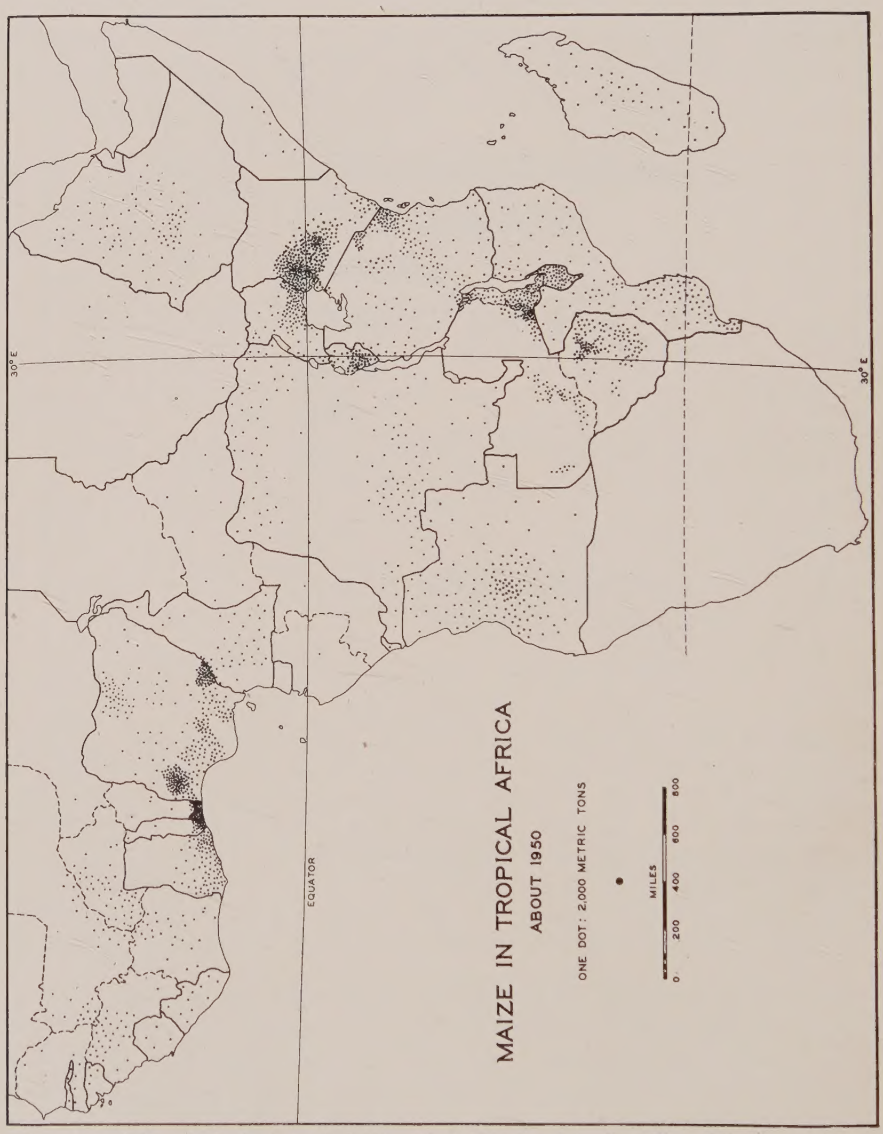

Figure 2. Maize production in tropical Africa, about 1950 (see Appendix to Figure 2 for sources of data)

East Africa's maize production is about two million metric tons, or close to half the tropical African production. West Africa accounts for a little over a quarter of the total, and Central Africa for slightly less than a fourth (*Table 1*).

In general, this production is rather evenly distributed (*Figure 2*). There are, however, a few distinctly heavy concentrations. One is Nyasaland and a relatively small region on its periphery. Northern Rhodesia and parts of Southern Rhodesia are such areas and the Bihé Plateau of Angola is probably another, although data are not yet available to confirm the impression one gets from qualitative sources. The Kenya highlands and the lake regions of Uganda stand out, as does Ruanda–Urundi. On the other side of the continent, southern Nigeria has two conspicuous pockets of production. One is in the Bamenda highlands of the British Cameroons, while the other has its centre about the city of Ibadan, near the country's western border. About 100 miles south and west, in lower Dahomey, is found tropical Africa's greatest concentration of maize production. Indeed, our map would have to be three-dimensional to make room for all the dots.

At the other extreme, there are a few areas, in some instances sizeable ones, in which little or no maize is grown. The largest of these, in the wet tropics characterized by heavy rainfall and dense tropical forests, extends through the centre of the Belgian Congo and the lower part of French Equatorial Africa. Almost none of the provinces of this region, from about 1° north to 2° south latitude in width, extending at least a thousand miles from the Atlantic Ocean almost to Ruanda–Urundi, reported as much as two thousand metric tons of maize production in 1950.

Other areas where very little maize is grown are dry savannah regions, such as regions bordering the Sahara and Kalahari deserts, where millets and sorghums, which are better able to withstand drought, predominate.

Production characteristics

Cultural practices in non-European farming are typically crude and yields are correspondingly low. Although production methods vary greatly in detail, it is generally true that: (*1*) hoe culture predominates and machinery is infrequently employed; (*2*) usually little care is given to the preparation of a seed-bed; (*3*) clean cultivation is rarely attained, either because maize is grown with other crops or because the farmer is unable to keep up with the growth of weeds; (*4*) improved seed is not typically used; (*5*) fertilizers are not commonly applied except, perhaps, on small plots around the dwelling where maize may be grown as a garden crop; (*6*) maize may receive some irrigation, along rivers especially, but irrigated maize is a small fraction of the total; (*7*) crop 'rotation' is essentially a question of crop sequences during the three or four years that land is under cultivation; (*8*) maize may be grown at any time in the sequence, but is most often first and seldom last.

The outstanding features of the maize harvest are that it is usually gradual and that very litle maize is harvested for forage. Harvest begins as soon as the ears are ripe enough to be used as a vegetable and continues well past maturity. Only a small fraction of the aggregate maize crop is harvested for feed (only European farmers commonly feed their livestock) and most of that appears to be for grain rather than forage.

Insects and diseases

Insects and diseases are serious problems for maize growers over all of tropical Africa. Of the diseases, mildews, leaf blights, smuts, and rusts are

the major problems (DE SCHLIPPE, 1956; MALLAMAIRE, 1949; BOURRIQUET, 1949). The most destructive and widespread of these is probably a rust, *Puccinia polysora*, which spread rapidly through Africa after its introduction in 1949, causing considerable, often catastrophic, damage—particularly in the more humid regions of West Africa. The areas of Pobé and Allada in Dahomey were so severely attacked in 1950 that a local food shortage occurred and the price of maize rose 500 per cent (CAMMECK, 1954*a*). During the same year many areas of Togoland, the Gold Coast (Ghana since March, 1957), and Nigeria reported a 50 per cent reduction in yields. The recent development of resistant varieties and the adoption of earlier planting dates have reduced losses considerably (CAMMECK, 1954*b*).

Stalk borers, ear worms, army worms, the corn-leaf aphid, grasshoppers, and locusts probably cause substantial yield losses everywhere, but available information is too fragmentary to determine the relative importance of each of these and the extent of the damage they cause.

*Table 2. Average maize yields for selected countries, 1945–49**

Quintals per hectare†			
Country	*Yield*	*Country*	*Yield*
United States	22·4	*Venezuela*	8·7‡
		Columbia	9·4
Ohio	32·2	*Philippines*	6·3
Iowa	30·4	*Ceylon*	5·4‡
Louisiana	10·9	*Java and Madura*	8·1‡
Florida	9·7		
Georgia	7·0	*Kenya*	15·0§
		Uganda	11·3§
Argentina	18·2	*Tanganyika*	9·1§
Austria	13·0	*Madagascar*	7·5§
France	10·1	*Nyasaland*	8·0§
Italy	17·6		
Spain	13·5	*Belgian Congo*	8·9§¶
		Nigeria	9·5§¶
China	13·5	*Dahomey*	5·0§¶
Brazil	12·9	*Gold Coast*	4·7§¶
Mexico	6·8	*Ivory Coast*	4·2§¶
Nicaragua	10·0	*Gambia*	4·2§¶
Cuba	10·0	*Senegal*	10·2§¶

* Data from U.S. Department of Agriculture, FAO (1954*b*), and sources in Appendix to *Figure 2*. Yield is generally equivalent grain yield on total acres harvested for all purposes, i.e. grain equivalent computed for acreage harvested for silage, fodder, etc.
† One quintal per hectare equals 1·59 bushels per acre.
‡ 1948–50.
§ About 1950.
¶ Yields probably somewhat lower than usual because of an epidemic of maize rust (*Puccinia polysora*).

Yields

As one might expect, considering the techniques of production and the prevalence of insects and diseases, yields are low compared with the major temperate belts of production‖ (*Table 2*). The relatively high yield reported for Kenya, 15 quintals per hectare, while high for tropical Africa, is hardly half that of Iowa, in the American Corn Belt. Perhaps more

‖ Tropical/temperate yield comparisons are not strictly valid. Because inter-cropping is commoner in the tropics, the number of maize plants per unit of land can be expected to be less than in the temperate zones; official estimates should correct for this, but it is not always clear that they do so. Even so, other factors, such as improved seed, fertilizers, greater care and frequency of cultivation, and the better control of insects and diseases, are probably responsible for most of the superiority of the temperate regions.

meaningful is *Figure 3* which suggests a modal yield for tropical Africa of around 5 quintals per hectare (8 bushels per acre)*.

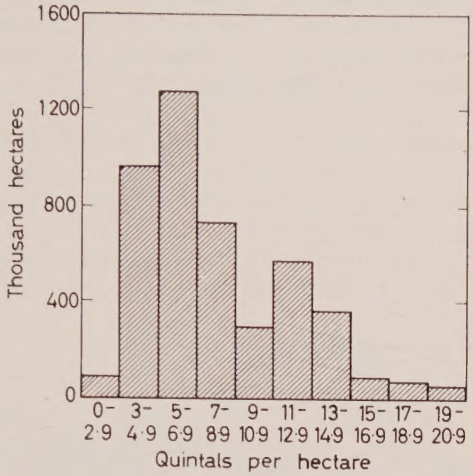

Figure 3. Tropical African maize yields by area, about 1950. [*Data from the same sources as Figure 2 (see Appendix to Figure 2), based on* cercle, *district, province, and major subdivision data. No yield estimates were available for Ethiopia, Liberia, Portuguese Guinea, and Zanzibar. One quintal per hectare equals 1·59 bushels of maize per acre*]

Unreliable and incomplete as the data are, there can be no doubt that yields are, as in most tropical countries, characteristically low. Whether they are low compared with other regions in the tropics is not clear and cannot be until better data are available, both for African and other tropical zones.

CONSUMPTION

In tropical Africa virtually the entire production is utilized as food; maize fed to domestic animals reaches significant proportions only on the European farms of East and Central Africa, and no record has been found of industrial utilization.

To obtain an approximation of *per capita* maize consumption, estimates of ' quantities available for consumption ' have been calculated on the basis of production plus net imports (or minus net exports), less allowances for seed and waste (stocks carried from one year to the next are insignificant). International trade in maize is of substantial importance only for Angola which exported an average of 113 thousand metric tons for 1948/49–1950/51 (FAO, 1954*c*). Internal trade data are not generally available, and no attempt is made here to take account of trade within countries. Hence, for districts which export or import a considerable volume of maize, the estimates presented in *Figure 4* are not a good indicator of actual consumption. Moreover, errors in the underlying estimates of maize production and

* The large acreage with yields around 12 quintals per hectare (19 bushels per acre) represents principally the southern parts of Ghana, the Ivory Coast, and Nigeria; the northern provinces and Katanga province in the Belgian Congo; and Northeastern Tanganyika. Yields above 15 quintals per hectare come from the European agriculture of Kenya and the Rhodesias.

population, which may, indeed, be large and not off-setting, introduce a further qualification. On the other hand, waste in preparation of maize is never large in tropical Africa, nor would one expect that much food would be prepared but not consumed. In general, *Figure 4* is probably a fairly good indicator of consumption. The relative importance of maize portrayed by it checks well with non-statistical information.

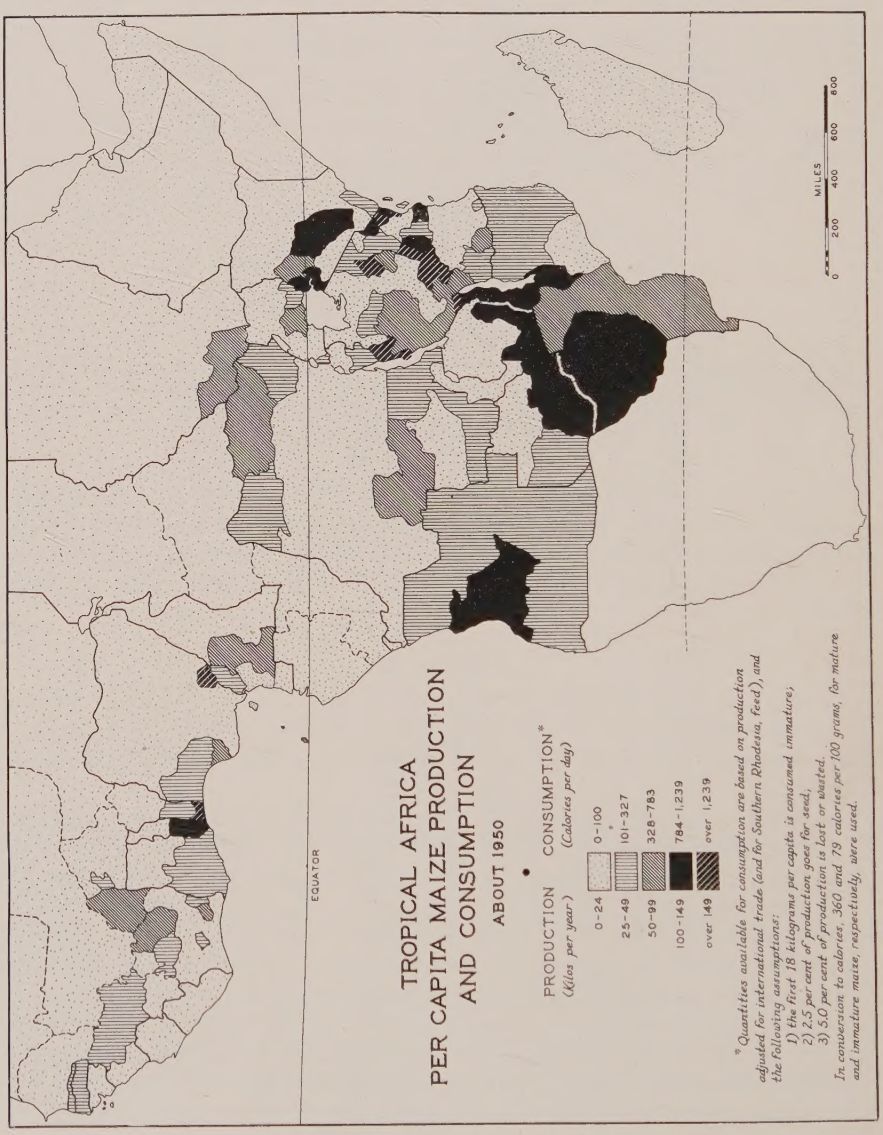

Figure 4. Per capita *maize production and quantities available for consumption in tropical Africa, about 1950* [*Population data are from official sources, in the main; where official sources were not used, information was usually obtained from* TREWARTHA *and* ZELINSKY, *1954, or from U.N.* Demographic Yearbook, *1952 or United Nations (1952). See Appendix to Figure 2 for discussion of production data*]

It was necessary to make certain assumptions in order to carry through these calculations. Somewhat arbitrarily it has been assumed that waste and storage losses are everywhere five per cent and that two and a half per cent of the crop was saved for seed.

Very little information is available about storage losses in tropical Africa. 'Some believe that the natives usually suffer very small losses in store,' says T. A. Oxley, who spent three months investigating grain storage facilities in East and Central Africa, 'while others believe that losses at the end of the season are very large indeed. My own observations shed little light on this' (Oxley, 1950). The loss figure of five per cent is in line with experience in India, although other bits of information suggest that this is unduly low. Within tropical Africa there must undoubtedly be great variations in storage losses reflecting differences both in climatic conditions and storage techniques.

Seed requirement estimates for tropical Africa are few, but those available and those for other tropical areas suggest that 2·5 per cent of production is not unreasonable (FAO, 1949; Mines Coloniales, 1954; Faulkner and Mackie, 1933).

Another difficulty is estimation of the size of the crop harvested immature, an important matter because the calorie content of immature grain is a little less than one third of that of mature grain (Chatfield, 1954; Platt, 1945). Because of the popularity of roasting ears, maize is nearly everywhere consumed immature as soon as ripening begins. It has been assumed that until 18 kg of maize *per capita* per year are eaten, maize is consumed immature only, i.e. the first 18 kg of consumption *per capita* is converted at the conversion factor for immature maize. Eighteen kilogrammes *per capita* per year is roughly eight half-pound ears or 630 calories per person per day for 21 days, which is probably the average period immature maize is available in regions where only one crop can be grown per year, and they account for the bulk of maize production (Smith and Dale, 1920; Manoukian, 1952*a*). Where more than one crop can be grown, the period is probably longer and therefore yearly consumption of immature maize presumably greater (Kaberry, 1952; Manoukian, 1952*b*; Dugast, 1954).

In Southern Rhodesia, Nyasaland, Kenya and Angola, qualitative information suggests, as do the aggregate data, that maize is the dominant staple for the majority of the population, usually accounting for half or more of the calories contributed by starchy staples*. These, plus the lower part of Northern Rhodesia, form the largest continuous maize areas, but pockets of maize dominance are found in Tanganyika, the Bamenda highlands of the British Cameroons, and the southern portion of Dahomey and Togoland.

Areas where maize may be the dominant staple, or at least a close second (areas of 327 to 783 calories *per capita* per day, *Figure 4*), are: southern Mozambique; portions of Tanganyika, Uganda, and the savannahs of the Belgian Congo; Zande district of the Sudan; southern French Cameroons; and a sizeable area extending from the northern portion of the Ivory Coast into the southern districts of Upper Volta. In most areas

* Based on a rough assumption of 1800 calories *per capita* per day with starchy staples accounting for 70 per cent of the calorie intake. Variations between ethnic groups resulting from differences in body size, age composition, and other factors are ignored because of lack of any basis for attempting such a refinement.

adjoining these, northern Mozambique, scattered areas in Tanganyika, Uganda, and the Belgian Congo, much of Angola, southern French Cameroons, western Nigeria, southern Ghana, and a zone extending from northwestern Ivory Coast to Gambia, maize is of modest importance (101 to 327 calories *per capita* per day). Over the rest of tropical Africa maize is a negligible item in the over-all diet, although it may be important seasonally.

Forms of consumption

Tortillas and cornbread, the principal forms of maize consumption in the tropical and temperate Americas respectively, are not eaten in tropical Africa. The principal way in which mature grain is consumed is as a thick porridge or a dough ball made of ground maize and served with a highly seasoned sauce. Maize beer is somewhat less widely consumed but is nevertheless common. Little is yet known about the extent and frequency of other forms of consumption (Barnes, 1948*a*; Charron, 1946; Jones, 1954; Cushmen, 1944; Southall, 1951; and Roscoe, 1911).

In western Nigeria maize may be boiled or roasted on the cob or the mature grains may be parched, boiled alone with beans, mashed alone or with beans, added to yam or banana loaf, or made into fritters or beer (Bascom, 1951*a*).

Boiled corn, boiled or roasted corn on the cob, and parched corn are the simplest preparations. To make mashed corn, kernels are soaked in wood ashes and water until the skins come loose, then boiled, and, finally, mashed. For steamed corn, the grain is ground after soaking, moulded, wrapped in leaves, and steamed. This is what is known in Mexico as *tamale*. For a steamed yam loaf, the grain is soaked, ground, moulded and added to the top of a pot of sliced yams. Then, after cooking, yams and maize are pounded and moulded into a loaf (Bascom, 1951*b*).

The most laborious and time-consuming product to prepare is cornstarch; but once it is made, gruel and porridge can be quickly prepared from it. To make cornstarch, dried kernels are soaked in water from one to four days, or, if needed sooner, they may be boiled for two or three hours. After soaking or boiling, they are rinsed, allowed to drain, and pounded in a wooden mortar. Next, water is added to make the skins float and they are skimmed off. The mixture is then strained, and the remaining loose particles and broken kernels are pounded or ground until fine. The final step is overnight fermentation. If gruel is desired, a small amount of starch is stirred into boiling water. Porridge is made the same way except that it is cooked to the consistency of a pudding or thick paste.

In Dahomey, various delicacies are made from maize. Best liked is a gelatinous dish made by cooking the juice obtained by pressing or crushing immature grains (Adandé, 1953*a*).

To make maize beer, the grain is sprouted, dried and then fermented until a thick brown brew is produced (Manoukian, 1952*c*; Barnes, 1948*a*; Adandé, 1953*b*; Monterio, 1876). It has a low alcoholic content (generally not more than 4 to 5 per cent) and will store only one or two, maybe three, days before spoiling.

Only relatively insignificant quantities of maize are used for feed in the African communities, and most of that probably goes to poultry. About

all that is fed is the bran and grinding offal (BARNES, 1948*a*; ADANDÉ, 1953*c*). Most Africans are too poor to feed their maize to domestic animals since 1000 calories of maize fed to animals can ultimately result at best, in no more than about 250 calories of livestock products (BENNETT, 1954). Even this rough estimate is probably high for tropical Africa because of the poor quality of most African livestock and the backward state of animal husbandry.

More maize is fed to livestock by European farmers. One gets the impression that the practice is fairly widespread in the Rhodesias (FAO, 1955), and presumably Kenya, but the total amount fed is quite small.

STORAGE

Reducing the moisture content of the grain to a level that permits successful storage (from 10 to 15 per cent depending on temperature) is a major problem in most areas, and is usually, but not always, solved by drying the harvest in the sun. Sun-drying is unnecessary when maize is stored by hanging the ears from the rafters or beams of the hut, for the open fire used for cooking will help lower the moisture content. In addition, the smoke helps repel insects and rodents.

Simple granaries are common. There is considerable variation in their design, but cylindrical bins, built off the ground, result in most instances, whether the construction is of bamboo, palm thatch, or a plaster of mud or cow dung applied to a framework of stakes (SMITH and DALE, 1920*b*; KABERRY, 1952; BARNES, 1948*b*; ADANDÉ, 1953*d*). Pits dug in the ground are also used (BROSS, 1954; IBRD, 1955).

PROSPECTS

At present it is only possible to mention some of the factors which will determine the future position of maize in tropical African agriculture.

Because maize is much more easily stored and transported than starchy roots and fruits*, is suited to a much larger geographical area than irrigated rice (at least until more irrigated land becomes available), and seems to compete successfully in consumption with the millets and sorghums, it is likely to supply a large portion of the increasing food requirements of non-self-suppliers (e.g. urban areas and mining communities).

If a sizeable livestock-feeding industry develops in tropical Africa, as it well may in the long run, it will probably rely heavily on maize, which as is well demonstrated in the United States of America, is a fattening feed *par excellence*.

Maize yields may well rise relative to those of its competitors as improvements in African agriculture are realized. Because maize has high inherent yield capabilities, there is much scope for large yield increases as improved seed, the use of fertilizers, and better cultural practices become widespread. In the European sector of Southern Rhodesian agriculture, for example, which employs production techniques much superior to those of the bulk of tropical Africa, hybrid yields were, on the average, 72 per cent higher

* Only flours or meals of these commodities (e.g. manioc flour) approach maize's storage and transport qualities. Not enough is yet known about processing costs to determine how much competition these products can offer maize, but it is perhaps significant that maize now appears to be more important than any of them in provisioning urban and mining centres of East and Central Africa.

than those of non-hybrid maize for 1949/50–1952/53 (Southern Rhodesia, 1954).

Because of the paucity of the data one cannot establish clearly, at this juncture, whether maize gains or loses, relative to the other major starchy staples, as incomes rise. However, it may be significant that in parts of Uganda, Kenya and Tanganyika maize appears to be gaining considerably in popularity (Uganda, 1950; Tanganyika, 1945; Tanganyika, 1952; Russell, 1954; Gourou, 1954).

Perhaps the introduction and spread of new methods of preparing maize will further strengthen its popularity. For instance, techniques of preparing tortillas, a thin maize flat bread, very popular in Mexico and other Central American countries where maize occupies a commanding position, have already been introduced into Southern Rhodesia (Bascom, 1951*c*).

APPENDIX TO *Figure 2*

Figure 2, an attempt to portray the geographical distribution of maize production in sub-Saharan Africa about 1950, is based on official statistics in most instances when they were available. For five territories, these were from sample censuses, which were part of the 1950 world census of agriculture.

The margin of error is undoubtedly large. Where transportation is poor and there is only small commercial production of the commodity concerned, one would expect estimation to be difficult and subject to considerable error; in addition, under-developed areas, almost universally, are too poor to afford good statistical services and colonial budgets have tended to be tight (Jones, 1955). Since several of these governments have not published statistics for all post-1945 years, an average of 1949–51, the period desired, was frequently impossible; only two of these three years were available in several instances and, for some territories, estimates of a single year had to be used. Nor was it possible always to obtain data within the 1949–51 range; 1946 was the earliest dating of any figures used—1953 the latest.

Data were taken from: *Annuario da Guiné Portuguesa 1948*, Publicacão do Governo da Colonia, Lisbon; *Annuaire Statistique de l'Union Française 1939–46*, Chap. F. France, Min. France d'Outre-Mer, Paris, 1949; *Annuaire Statistique de l'Afrique Occidentale Française*, Vol. II, Haut Commissariat de l'Afrique Occidentale Française, Paris, 1951; *Marchés Tropicaux du Monde*, 24 Nov 1956; *Annual Report—1st April 1952 to 31st March 1953*, Gold Coast Dept. Agr., Accra, 1954; *Report on the Sample Census of Agriculture 1950–51*, Nigeria, Dept. Stat., Lagos, 1952; *Ager*, Boletín de la Dirección de Agricultura de la Guinea Española, Vol. 4, Jan–Jun, 1954; *L'Agriculture au Congo Belge et Ruanda Urundi 1948–1952*, Belgium, Min. Col., Brussels, 1954; *Plan décennal pour le Développement Economique et Social du Ruanda Urundi*, Belgium, Min. Col., Brussels, 1951; *Yearbook of Food and Agricultural Statistics 1953, Part I: Production*, Food and Agriculture Organization of the United Nations (FAO), Rome, 1954; *Non-Self-Governing Territories, 1952*, Vol. II, United Nations, New York, 1953; *Annual Report of the Department of Agriculture, 1951*, Uganda, Entebbe, 1952; *Tanganyika Blue Book for the Year Ended December 31, 1948*, Tanganyika, Dar-es-Salaam, 1950; *Seventh Report on the Agricultural and Pastoral Production of European Farmers, 1952–53*, Southern Rhodesia, Salisbury, 1954; *Annuaire*

Statistique de Madagascar 1938–1951, Vol. I, Haut Commissariat de la République Française à Madagascar et Dépendances, Tananarive, 1953; and data made available by M. J. MIÈGE of the territorial government of the Ivory Coast, M. THOMAS of Dahomey, and the Northern Rhodesian Department of Agriculture.

For Mozambique, production was estimated from a description of the importance of maize in the diet (40 per cent of staple foods consumed—information provided by R. Smith Simpson, American Consul-General in Mozambique), assuming that staples contribute 70 per cent of total calories and that, on the average (including children), 1800 calories are consumed *per capita* per day.

For Uganda, production was calculated from acreage and average yield data. The following yield estimates for provinces, based on average yield statistics for all of Uganda and rainfall data, were used (quintals per hectare): Buganda, 14; Eastern, 11; Western, 8; and Northern, 8. Within these provinces yields were assumed to be uniform.

For Zanzibar, production was estimated from acreage, assuming a yield of 10 quintals per hectare.

Where data could be obtained for small administrative divisions, distribution was assumed to be uniform within each *cercle*, district, or province to which the data referred. For most of French West Africa these were *cercles*; for Uganda, Tanganyika, and the Union of South Africa, districts; for Nigeria and the Belgian Congo, provinces; for Portuguese Guinea, Ghana, French Cameroons, French Equatorial Africa, Ruanda–Urundi, and Northern Rhodesia, only a breakdown by major subdivisions could be obtained. Where no breakdown of statistics was available—for Gambia, Rio Muni, Sierra Leone, Zanzibar and Pemba, Nyasaland, Liberia, Sudan, Ethiopia, Kenya, Somalia, Mozambique, Angola, and Southern Rhodesia - the method of distributing dots depended on the size of the territory. The first five of these are no larger than some of the provinces in other territories, hence dots were distributed uniformly. But for the sizeable territories (the last eight named), non-statistical information—descriptions of agriculture in the various regions (including descriptive maps), letters from administrators, rainfall and population maps, and the location of centres of European agriculture—was utilized to obtain a rough first approximation of the geographical distribution of maize.

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Agricultural Research and Development in the Southwest Sudan

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PART II: THE PROBLEM OF SOIL FERTILITY

THE PRIORITY RESEARCH PROBLEM

From the earlier discussion in Part I it is evident that the future development and prosperity of a region such as the southern Sudan, remote, primitive, and devoid of mineral resources, must depend on the right use of this very considerable land area for agriculture and forestry. To implement this objective the working out of a scientific agricultural system, adapted to the needs of local conditions, is the first duty of agricultural research. This realization is reflected in Sir Daniel Hall's statement (Hall, 1936) that: ' The first necessity in these agricultural communities of Africa is a change from shifting cultivation to fixed agriculture, to a recuperative system of farming which will maintain cultivation indefinitely on the same land '. While it is possible to define the problem it has not so far been possible to devise any satisfactory solution to it, in spite of a good deal of effort and research. Indeed it must be admitted that no neat and tidy solution can be expected for a long time. Hitherto, in the rain-lands of the south, most of the experimental work has been devoted to the improvement of existing varieties of food crops and of cotton, and to the introduction of new plants, while work on the problem of crop management is in its infancy.

All that can be said at present is that some tentative approaches have been made, one of which was the recent study of a hitherto neglected problem, viz. the extent of the cultivable land available for agricultural expansion and land use in an area of the southern Sudan (Willimott, 1956). The absence of land use surveys in underdeveloped countries makes it impossible to formulate other than generalized schemes of development. In this investigation it was shown, *inter alia*, that about 87 per cent of the total land area of Equatoria Province west of the Nile was available for agricultural development although water supply is a limiting factor in many parts. Of this area less than two per cent was in actual cultivation in any one year. A sparse population is one of the significant factors in the problem of agricultural development. From some close acquintance with this region it is now possible to put forward certain logical proposals for future work in research and development in the south.

There are, however, two natural resources which suffuse the situation with some hope; the abundance of land and the natural cover of trees and grass that protects it. On the logical development of the one, and the wise management of the other, the future prosperity of the southern province may well depend. With an almost limitless potential of cultivable land per head of population, the system of shifting agriculture, or ' leaving it to Nature ',

follows logically under present-day conditions. There is thus no land hunger in the south and most of the agriculture is on a subsistence level. Because shifting agriculture is wasteful of land, labour and time, it is the duty of agricultural research to devise if possible a more scientific system of peasant agriculture. Under present conditions the problem may not be one of immediate urgency, but as soon as future development with increasing population is considered, this must assume priority in any research programme. The justification for the study of more intensive land use on experiment stations is that we need to know how to use land more economically against the day when the population will have increased to the point where there is not enough land for the current shifting cycle.

SHIFTING AGRICULTURE

Without going into details, in this system a crop is brought under cultivation for about three years and the peasant farmer then shifts to new ground, usually untouched virgin bush. The land is abandoned when the crop yield collapses after three years' cropping or when weeds, such as spear grass (*Imperata cylindrica* Beauv.), black jack (*Bidens pilosa* Linn.) and *Eragrostis* spp., invade the exposed soil. In the wetter regions, regeneration of vegetation in the bush-grass fallow is rapid and effective after a period of anything up to 12 years. Even granting a wide variation in length and composition of the bush fallow it is still a matter of debate as to whether soil fertility is even then completely restored. It is noteworthy that in the excellent ' Paysannat System ' of the Belgian Congo no shorter fallow is feasible in the tropical rain forest. For these reasons the maintenance and improvement of soil fertility to secure the maximum possible crop return has been accepted as the main objective of research at the Yambio Experimental Farm.

Table 1. Equatoria Province west of the Nile: area and population

District	*Sq. miles*	*Feddans*	*Population (approx.)*	*Population density per sq. mile*	*Admin. H.Q.*
Juba	7503	4624849	63000	8·4	*Juba*
Moru	13800	8506320	67200	4·9	*Maridi*
Yei	6232	3841405	111400	17·9	*Yei*
Zande	17534	10807958	168369	9·6	*Yambio*
Total	45069	27780532	409969		

The system of shifting agriculture has advantages as well as disadvantages. By leaving an exhausted plot to regenerate its fertility by natural processes the labour and expense of manuring is avoided. Moreover, with small separate plots of one or two feddans or less, the damage caused by pests and disease is minimized. Shifting agriculture, with its long resting period, is in effect a modified form of crop rotation. Its disadvantages are its inherent wastefulness of land, requiring as it does about five times the area of land needed for modern methods of cultivation in temperate climates, and the small units of land involved. The population density by districts has been studied and shown to be of the order of 9·1 per square mile in Equatoria Province west of the Nile and 7·1 east of the Nile (WILLIMOTT, 1956). Data on population densities by districts are summarized in *Table 1*.

In Zandeland, the present trend is for the population to decrease because of the continued infertility of the Azande due to the high incidence of venereal disease; and secondly, some movement of tribesmen has recently taken place across the frontiers. These population data lend support to the view that shifting agriculture, with some modifications, is the only system practicable under present conditions. The sparseness of population is therefore another obstacle to development.

SOIL FERTILITY AND THE ANNUAL BURN

Inherent in the system of shifting agriculture is the practice of burning dry vegetation annually. With the exceptions of the gallery forests and depression forests such as Azza and Lotti, fortunately too green to fire, burning is universal in the southern Sudan. Throughout tropical Africa it is carried out almost as a religious rite. Because of the dangers of erosion, destruction of soil structure and microflora, leaching and consequent loss of soil fertility, the practice has little to recommend it, even when confined to the organized cool early burn. When carried out later in the season the fierce fires and high flames inflict permanent damage, which is cumulative, both to soil and vegetation. Not only is the valuable humus destroyed but some phosphate and sulphur must also be lost by volatilization through the high temperatures generated, although experimental proof is still lacking. Aerial photographic reconnaissance has shown that over extensive areas in the south almost complete denudation has resulted from uncontrolled burning. Even at 15 000 feet observers have recorded the presence of large specimens of carbonized vegetation caught up in the extensive air turbulence created by large fires. This is scarcely surprising when it can be recorded that a grass fire at Ti Vura (Yambio) in the dry season of 1955 was observed to scorch the upper canopy of an isolated kapok tree 100 feet in height.

Jewitt (1949) rightly contends that the annual grass fire changes the traditional Zande system into a rotation of cropping followed by cropping-by-burning. He points out that the annual destruction of the vegetation leaves the land exposed to the oncoming rains with mineral nutrients lying vulnerable upon the surface as ash or in charcoal. Some recent analyses of typical carbon and ash residues, resulting from the burn in different localities, are given in *Table 2*.

These data show that a considerable percentage of the total plant nutrients present are locked up in forms unavailable to the plant. Whether available or not, all such mineral nutrients are at the mercy of wind and rain, and are to a large extent lost to the soil cultivated. Little is at present known of the order of these losses in a given soil in any one season. A quantitative investigation of the plant ash remaining after (*a*) a cool burn, and (*b*) a hot burn could throw much light on this problem and a start on this work has been made at the Research Farm.

It is not always realized that the long continued practice of the annual burn has caused the suppression of all but the fire-tolerant species of trees and grass. In effect, and in the absence of plantation agriculture, a sparse nomadic population has succeeded in transforming the main character of the standing flora over vast areas of Central Africa. Associated with the widespread annual burning is the appearance of almost pure stands of

Imperata cylindrica Beauv., one of the noxious weeds of the tropics in abandoned cultivations and fallows. On the other hand Imperata counteracts erosion by its rhizomes and by flourishing even in the dry season and so shading the soil. Under normal conditions such land would not be cultivated again until the Imperata had been replaced by other more useful grasses. The annual burn is a serious obstacle to this replacement because the underground rhizomes of the perennial Imperata can withstand fire whereas the seeds of these valuable annual grasses, which do not develop underground rhizomes, are destroyed.

Table 2. Ash content from different residues from the annual burn

Sample No.	*Origin*	*Vegetation*	*Moisture per cent*	*Ash per cent*
1	*Yambio Experimental Farm, Yambio*	*Long grass and bush fallow. Just after burning*	1·90	85·45
2	*4 miles, Yambio–Nzara road*	*Recent burn in a fallow, grass and regeneration*	2·60	82·17
3	*Sugar Cane Plantation E.P.B., Sakure*	*Ash from factory bagasse*	1·73	81·93
4	*Maridi–Ibba road*	*Bush*	1·91	80·26
5	*Bamboo forest, Yei–Maridi road*	*Pure bamboo stands*	2·51	43·74
6	*Azza State Forest, 30 miles S. of Maridi*	*Long grass in marginal depression*	4·08	27·37
7	*Hilly country east of Lui*	*Grass woodland*	1·08	66·36
8	*Ti Vura, Yambio*	*Recent burn.* Imperata *grass*	2·83	71·78
9	*Y.E.F., Yambio*	*Virgin bush. Just burnt*	2·18	82·54
10	*Y.E.F., Yambio*	*Bush regeneration*	2·36	73·16
11	*Wood ash for comparison*	*Domestic use*	1·78	78·08

Annual burning has thus been practised long enough to bring about a direct transition from primaeval forest to savannah forest, i.e. from a primitive climax to a sub-climax. A distinguishing feature of this secondary formation is that it is much more easily penetrable by fire than primaeval forest, which is in fact not inflammable. Primitive forest once destroyed rarely if ever re-establishes itself.

INCREASING DESICCATION IN AFRICA

The corroding influence of fire thus results in the gradual impoverishment of all vegetation. Deterioration proceeds in stages from primaeval forest through savannah to poor grassland and ultimately to surface sheets of infertile laterite, known in the south as *mungas**. Taking Africa as a whole, this movement has had adverse effects upon the hydrologic cycle, tending in general to produce a greater potential in evaporation from the soil surface with a corresponding decrease in contributions to the underground reserves of the ground-water table. As WHYTE points out (1949), these factors have given rise to the problem of increasing desiccation in Africa (the so-called 'advance of the desert', *vide* STEBBING, 1953), especially in the territories bordering the Sahara and Somaliland. In fact, as in other parts of the tropics, the rainfall is not so much decreasing as becoming less effective, due to increased run-off and evaporation.

* *Munga* is the Zande term for surface laterite outcrops with characteristic mushroom-shaped termitaria and dwarf grasses.

According to the French forestry authority, LOUIS LAVAUDEN (1935), the regression of the equatorial forest in Africa goes far back in geological time and, in his view, there is little doubt that at the beginning of historical time this forest was much more extensive than it is today. He considers that the final retreat of the great glacial extension in Europe brought about in turn a period of dryness, which has gradually increased in intensity to the present day. To this are mainly attributed the formation of the Sahara and the relative desiccation of the Sahel (the western edge of the Sahara) and the Guinea zones, although human agency has greatly accelerated the process. Lavauden believes that the equatorial forest extended as far as Merowe, 200 miles directly north of Khartoum, which today is surrounded by semi-desert. Thus in 20 centuries the equatorial forest has retreated almost ten degrees southwards. Not only have natural agencies contributed to this vast regression, but the primary agency has been the hand of Man. Lavauden cites, for example, the use of fire as the sinister auxiliary of the slave traders as one of the factors determining this regression. Finally he claims that in certain areas the regression can be established at about 30 kilometres over a period of 50 years.

SOIL FERTILITY AND TREE CROPS

Apart from the meagre patches under cultivation the most striking feature of a journey across Equatoria from Juba on the Nile to Nzara, 350 miles to the west, is the uniform expanse of the broad-leafed, high grass woodland affording natural protection to the soil. To the observer Nature seems to be continually offering the suggestion that tree crops in some form or another are the answer to the soil fertility-crop production problem of the south. Indeed, the tree crops already introduced, mango (*Mangifera indica* Linn.) and *Citrus*, are already a distinguishing feature of much of the province west of the Nile. SMITH (1950) has shown that there is a close correlation between the distribution of particular tree species and rainfall and soil texture, jointly evaluated.

It is now accepted that a host of soil problems arises as soon as the natural tree cover, whether forest or bush, is cleared and the soil exposed. Happily, in spite of the savage system of the annual burn, Nature still succeeds in the struggle to conserve soil structure and fertility by means of the standing cover of trees and grass. The fact that trees are able to take care of their own soil needs and nutrient requirements is not so generally appreciated. Trees are so much better adapted to await the rains and to utilize them to the full when they come than are annual crops. Trees can make use of soil moisture far better than annuals because of their deeper rooting systems which enable them to withstand conditions of drought and nutrient deficiencies. The mosaic of the leaf canopy is able to break up the raindrops of tropical storms, when four inches of rain or more may descend in a single storm, thus preserving soil structure and minimizing leaching. Trees are far better adapted to withstand the drought of a dry season or the short intercurrent droughts of the wet. Their extensive root systems hold the soil in position and counteract erosion. In short, tree crops safeguard fertility while producing food for man and beast. Tree crops once established require less care and maintenance and are in fact a feature of permanent agriculture. They are

equally suitable for the hill or plain, and wherever poor and rocky soils preclude the raising of other crops. Professor Smith has discussed (1954) in detail the thesis of the valuable economic products to be derived from trees in contrast to typical annual crops, which require much attention and provide no permanent cover for the soil.

Although the contrary is well known to pedologists, there still exists a fallacy that the presence of the tropical forest necessarily indicates soils of great fertility. From the standpoint of agronomy there is no necessary relation between the quality of the soil and luxuriance of the primaeval forest that it may support. In equatorial regions soils of poor nutrient status often carry magnificent forests capable of persisting indefinitely if not disturbed by man. Even in the lateritic country of Equatoria some of the thickest bush is carried by light shallow soils with a high content of pea iron gravel (*murram*). In other cases trees can be seen growing on massive lateritic outcrops twenty feet thick and splitting the rock. In lateritic country such outcrops occur on the so-called ' breakaways ' and in the vicinity of extensive sheets of solid ironstone (*mungas*).

It has been rightly said that the tropical forest works on a small capital of nutrients with a rapid turnover. This capital of plant nutrients in a mature soil is locked up mainly in the living vegetation and the humus layer supplied by the leaf fall and dead wood, which form an almost closed cycle. The system thus represents a state of dynamic biological equilibrium. The small losses of nitrate and minerals due to leaching are offset respectively by the nitrogen compounds returned to the system in rain water and by the tapping of the resources of the parent material. For the elaboration of the cellulose and lignin comprising the forest timber (material with widely varying C/N ratio), most of the needs of the equatorial forest are supplied by the carbon dioxide of the atmosphere and the water of the soil. Thus the primaeval forest is in no true sense a product of the soil. It is noteworthy also that the poverty of the soil is matched by the poverty of utilizable timber to be extracted economically from this huge mass of vegetation (LAVAUDEN, 1935).

THE SOIL ORGANIC MATTER

It seems remarkable that the soil can be so low in organic material when the luxuriance of the primaeval forest is considered. Newcomers to the tropics are often amazed to find only an inch or two of darkened topsoil in the heart of the bush and to discover areas entirely devoid of humus. In Equatoria, where conditions are perhaps more favourable, the A horizon in virgin bush is represented by approximately nine inches of topsoil (*vide* ANTHONY and WILLIMOTT, 1956).

The fertility of the soil is intimately bound up with its status in organic matter. In opening bush for cultivated crops this vital constituent becomes vulnerable to the effects of insolation and temperature immediately the natural tree cover is cleared. In plantation development the hazards on clearing forest are obviously greater than in the smaller plots involved in shifting agriculture. It may be useful to consider briefly the results of relevant investigations in other parts of the tropics, which have a bearing on this important problem. Because of the cost involved it will have been realized

that the use of artificial fertilizers for the maintenance of soil fertility in the south at present offers no practical solution. The soil organic matter is almost entirely derived from the plant residues which cover the forest floor and its magnitude in the thick bush of Equatoria, although undetermined, must be considerable. Some idea of the order of magnitude may be gathered from the finding of D'Hoore (1953) that the equatorial forest of the Belgian Congo produced 12 tons of dry litter per hectare per annum, or nearly five tons per acre. The excreta and dead bodies of animals can add but a small quota to the total.

The combined nitrogen present in the soil comprises contributions from the breakdown of plant residues to humus, from the ammonia and nitrate acid brought down by rainfall, and by the agency of symbiotic bacteria in the root nodules of leguminous plants. Although under natural conditions plant residues must supply the major portion of the soil nitrogen, considerable amounts may be contributed by rain water and by symbiotic bacteria. From observations in the field the degree of nodulation in legumes is poor in the south and its role in soil amendment by nitrogen fixation in the tropics may have been over-estimated, as compared with known effects in temperate climates (*vide* Masefield, 1957). This effect may be associated with a deficiency of trace elements or essential microflora in the soil but nothing definite is known. If this is so it might furnish an explanation as to why leguminous crops and green manuring in the tropics are often without significant effect on the nitrogen status of the soil. On the other hand, the amounts of nitrogen annually returned to the soil in rainfall may be considerable, if variable, thus providing a more important reservoir of available nitrogen than has been suspected. No precise information is available in this area and an investigation into the problem would be of great practical and scientific interest.

The study of the fate of the organic matter on clearing the forest cover and exposing the soil to solar radiation ranks as one of the critical research problems of tropical agriculture. Although the mechanism is by no means fully understood, much light has been thrown on the relationship between the soil temperature, humidity and the content of nitrogen and organic matter in the soil by the researches of Jenny in the United States of America (1928 to 1932 incl.), of Mohr and van Baren in Indonesia (1930, 1954), and of Corbet in Malaya (1934, 1935). Investigation has centred around nitrogen as being the nutrient of most interest to the cultivator because it has proved so often to be the limiting factor in crop production (*vide* Anthony and Willimott, 1955).

In the presence of an adequate supply of moisture and air Mohr showed that the optimum temperature for humus accumulation differs from that for humus destruction. The degree to which organic matter accumulates in the soil thus depends on the mean annual temperature. Mohr distinguished microbiological decomposition under both aerobic and anaerobic conditions and represented such systems by graphs. From these data it is evident that humus accumulation can take place in the tropics only at temperatures below 25°C but at temperatures above 25°C humus destruction outstrips its formation. In Malaya, where the humidity factor may be taken as constant, the mean soil temperature in the forested plains is 25°C. Hence

Corbet concludes that the nitrogen content of the soil in Malaya remains about constant. In Equatoria, with its three months dry season, there is more seasonal variation in soil temperature and humidity. Few observations have been made but preliminary records suggest a build-up of humus during the long wet season and some breaking down in the dry. The subject merits further detailed investigation.

In his series of papers Jenny has shown that the nitrogen (and organic matter) content of the soil varies inversely with the mean annual temperature and directly with the humidity. This finding was expressed as a mathematical relationship, known as Jenny's law, and its conclusions are of great importance to tropical agriculture. Corbet (1935) applied the law to Malayan soil conditions and concluded that the nitrogen content of the soil also decreases with the amount of direct solar radiation received. From Corbet's studies it appears that the mechanism responsible for nitrogen losses is chemical, not microbiological, and that increased insolation is responsible for photochemical change resulting in the breakdown of humic material to free nitrogen and carbon dioxide with smaller quantities of ammonia and nitrate.

From these conclusions it is possible to envisage more clearly some of the consequences which follow clearing of the bush and exposure of the soil to the tropical sun in clearing operations. Such treatment has the immediate result of raising the soil temperature above the critical point, causing losses of nitrogen from direct irradiation, and a complete cessation of any addition of organic matter to the system. The nitrogen losses are considerable and probably proceed at a greater rate than is supposed. Before equilibrium can be attained the organic matter content of the exposed soil must fall to a new and lower level in accordance with the considerations discussed above. Only by the subsequent appearance of a vegetative cover and consequent shading of the soil, can the organic matter content be permanently increased.

BAT GUANO DEPOSITS

Other methods of conserving soil fertility are by the application of systems of crop rotation, mulching, and the use of locally available fertilizer amendments such as compost and guano. The first method is now reasonably established in native agriculture. Mulching is practised on existing tree crops, on the Haggar coffee plantation at Iwatoka and small Government plantations, but is rarely found in general peasant practice and never with annual crops. Mulching of cotton has been tried experimentally at the Yambio Experimental Farm with encouraging results, favouring a light 3 in. grass mulch (ANTHONY and WILLIMOTT, 1955). The cost of mulching is to some extent offset by reduction in weeding costs. A thich grass mulch (6 in.) usually has either no effect on yield or actually depresses it; this effect is probably associated with a lower soil nitrate level. In addition work on tie-ridging has been initiated. Results are provisional but promising.

Two locally available fertilizers, bat guano and compost, are of some practical importance. Taking the question of guano first, it has long been known that a cave existed near Mupoi, bordering on the thickly wooded khor* of the River Madoro in Equatoria, and containing a considerable

* *Khor*—pl. *Kheiran*. A seasonal water course.

deposit of bat guano, somewhat leached. In the past this fertilizer has been used successfully to establish the *Citrus* groves and vegetable gardens of the Verona Fathers Mission at Mupoi. The cave, the largest known in the south, is 50 metres in length and 12 to 20 metres in breadth with a height varying from 2 metres at the sides to 5 metres in the vault (WILLIMOTT, 1953).

Starting from this point various caves, reputed to contain bat guano and located throughout the province, have been surveyed by the Soils Section of the Research Farm. Many have been located and the more promising have been investigated and samples of guano analysed. It has been found that most of the caves are small in size with correspondingly limited deposits and that they are widely distributed, often in remote places. The quality of the guano, however, is high as can be judged from a perusal of the analytical data given in *Table 3*. Acknowledgements are due to the Government Analyst, Khartoum, for these data. Moreover the physical condition is such that the guano can be applied immediately to the soil. Analyses of the deposits at different depths showed that the surface horizon was richer in plant nutrients, affording evidence of leaching by water.

Table 3. Analyses of bat guano samples from Equatoria (after Sudan Government Analyst, 1954–55)

No.	*Ash*	*Nitrogen %*	P_2O_5	K_2O	CaO
1	12·8	9·2	5·0	5·8	1·1
2	14·8	8·5	3·3	1·5	1·3
3	13·5	8·1	4·8	3·5	1·1
4	11·2	10·6	4·3	2·4	0·7
5	17·1	7·9	5·7	6·1	1·3
6	13·3	11·3	5·2	2·3	0·8
7	16·6	10·0	6·0	2·1	1·4
8	45·0	6·2	3·5	1·1	0·6
9	9·5	11·1	3·3	1·2	0·4
10	41·1	5·3	4·5	0·3	0·5
11	12·2	4·3	4·8	1·9	0·8
12	50·3	10·4	2·0	0·9	0·4
13	56·0	2·9	3·7	4·5	5·4
14 (*Mupoi*)	49·9	2·8	4·1	0·6	—

Observational trials have shown that wherever these naturally occurring guanos have been applied as fertilizer they have exerted a marked beneficial effect on crop yield, especially with the food crops. Reports indicate the existence of larger caves with more extensive guano deposits in the Moru district but it was not possible to examine these owing to local conditions. It seems likely that their investigation would be rewarding. The conclusion is that such natural deposits, small and scattered though they be, should be exploited to the full in a land of no fertilizers where hunger is never very far away.

COMPOST

Virtually no use is made of compost by the peasant farmer. In Zande district, although each household has considerable refuse heaps of undoubted manurial value, application of household refuse to crops is taboo. The study of the use of compost in local agricultural practice, as another approach to the general problem of soil fertility, was undertaken by T. P. Hall, former Principal of the Agricultural Training School, Yambio (HALL, 1954).

Hall suggested that crops, in particular cash crops, should be grown in trenches filled with compost. A holding could be divided into an area of about two feddans (60 m × 150 m) which would be used for cropping, while about three feddans (90 m × 150 m) would be maintained under bush as a source of compost. Within the bush area, a system of rotational cutting would be devised to allow plots supplying vegetation for compost production to regenerate adequately. The intensity of the cutting cycle would vary with soil fertility. Hall suggested that compost be made by the simplest method, viz. by placing material obtained from the bush fallow in heaps adjacent to cultivated plots, and he stressed the need for the prohibition of burning if optimal results were to be obtained. Hall incorporated these ideas in a simple experiment, and the results are given in *Table 4*.

Table 4. Comparative crop yields in compost and soil

Crop	*Treatment*	*Yield* (rotls per feddan)*	*Plant population of planted area*	*Average height of plant (cm)*
Seed cotton	*Soil*	501	7100	92
	Compost	707	5800	112
Groundnuts (unshelled)	*Soil*	742	2920	41
	Compost	1239	2722	53
Eleusine (grain)	*Soil*	840	—	—
	Compost	1176	—	—

* 1 rotl/feddan = 1 lb/acre (approx.).

Although these results have not been analysed statistically, and refer to one season's cropping only, they suggest that by growing cash and food crops in locally made compost substantial yield increases can be obtained. Similar results have emerged from experiments with vegetables. It still remains to be seen whether an area of three feddans can supply the compost needs of the average household, and the speed of compost decay in the soil is also unknown. Original compost has, in some instances, been employed for a second season, and where regeneration of bush proceeds at a normal rate three feddans is probably an adequate area for compost supply.

The manurial value of compost requires fuller investigation, since few composts have so far been analysed in the Sudan (Snow, 1952). Analyses of two different types of compost used in the Yambio experiments are given in *Table 5* below.

Table 5. Composition of compost used at Yambio

Sample	*A* %	*B* %
Moisture	3·22	27·35
Ash	82·22	63·91
Calcium (as CaO)	0·49	0·32
Potassium (as K_2O)	0·22	0·25
Nitrogen (as N)	0·41	0·29
Phosphorus	*Nil*	*Trace*

These field studies should be developed in the favourable conditions of the south, since Hall's method may prove a simple, economical and practical contribution to the problem of regenerating and maintaining soil fertility.

THE PLACE OF ARTIFICIAL FERTILIZERS

It has already been pointed out that the use of bat guano and of compost should be exploited to the full. However, for the maintenance of soil fertility under more intensive cropping the contribution of bat guano might indeed prove to be a drop in the ocean of the nutrient needs of southwest Sudan. Compost, on the other hand, can be regarded as a practical means of turning over the existing fertility resources of the area. Under present conditions with a sparse population these resources, systematically applied, might perhaps prove to be adequate. But under any system of intensive cropping the suspicion is that compost also would prove to be inadequate. If this is so some means of adding to the sum-total of soil fertility from outside the agricultural system must be devised. This can only be done by the use of artificial fertilizers.

Although the economics of fertilizer application (both major and minor nutrients) preclude their use at present, the agricultural research worker must still study their scientific application. In the first instance, this has to be done in order to determine what the needs of the soil are and whether there is any significant reward in crop yield from their use. By this approach the use of artificials in field experimentation can offer valuable clues to the identity of the limiting factors in plant nutrition by comparison of crop response with certain analytical evaluations. The appreciation of the importance of this aspect of agricultural research formed the basis of much of the field experimental programme at Yambio.

For a long time it has been almost an article of faith with many tropical departments of agriculture that the peasant could not afford fertilizers and therefore the research worker should not waste his time on them. The result has been that frequently there has been scarcely a shred of evidence on which to base advice. If the present research policy is continued in the southwest Sudan there should be no lack of such vital information for the peasant cultivator when more prosperous times return.

MAJOR CROPS FOR DEVELOPMENT

Here it will be necessary only to outline the development of some staple tropical crops leaving a more comprehensive discussion to a later paper. Of these major crops, sugar cane is a typical perennial, capable of being developed by mechanization on the plantation scale. It prefers a fertile alluvium and economic success depends on an adequate land area of good fertility and on cheap communications. These desiderata are to be found in the riverain flood plain of the Nile and the higher land above the flood plain for irrigation, in the region between Juba and Bor. This appears to be the most promising area for sugar cane development on the plantation scale. Some preliminary work has already been done by private interests but the project has scarcely reached the pilot stage.

The importance of coffee in the agricultural economy requires no emphasis. The Haggar coffee estates at Iwatoka, situated about 40 miles south of Yei

on the Aloma plateau, are the only example of successful plantation agriculture in the south. They extend to 650 feddans, mainly planted to *robusta* coffee grown without shade. One third of the plantation is irrigated and the rest mulched. Plantations apart, coffee cultivation could be greatly extended and incorporated without much difficulty into peasant systems. Suitable soils are no doubt limited and dispersed but *robusta* could be raised in the 'green' belt, *excelsa* in the drier 'red' and perhaps *arabica* in the west. In *Table 6*, analytical data on three representative samples of soil from the Iwatoka plantation are summarized. Suitable sites for coffee are to be found along the banks of *khors* and valleys where better loams exist of good water-retentive capacity. The possibilities for tea are considerable and a start has been made in the Imatong Mountains and Yambio. But much further trial and experimentation are necessary.

Table 6. Haggar estate, Iwatoka, Equatoria province

Block	*Tea*	*New*	*Coffee*
Soil sample	1	2	3
Nitrogen (Kjeldahl) p.p.m.	2 230	910	2 560
Organic carbon (Walkley Black %)	3·642	1·544	4·056
C/N *ratio*	16	17	16
Available P_2O_5 *(Truog) p.p.m.*	50	60	50
Available K_2O *(Cobaltinitrite)* mg%	0·038	0·043	0·050
pH *(approx.)*	7·0	6·5	7·0
Soluble salts	*Very low*	*Very low*	*Very low*

Thanks are due to Mr G. W. Worrall, Lecturer in Pedology, University of Khartoum, for supplying these results.

Oil palm culture is a feasible project both for peasant and plantation cropping and may prove to be less exacting as regards soil and climatic requirements than coffee or tea. Already it has been demonstrated that the roots of the oil palm can penetrate successfully the pea iron gravel horizons of Equatoria soils. Because of soils of low fertility and the water limitations of the dry season, it cannot be argued that these plantation crops are in their optimum ecological environment. Nevertheless, soil and climatic conditions are probably suitable enough to produce a yield not below the economic threshold.

Amongst other tree crops yielding edible nuts and oils are the cashew (*Anacardium occidentale* L.) and the pachira nut (*Bombax sessile* Benth.). It is now well established that these crops grow well in this area on soils of low fertility. Provided that an adequate organization can be built up to deal with the harvest the future for these crops is promising. With the pachira nut, which yields 43 per cent of edible oil, the composition of the fatty acids has been shown to be identical with that of palm oil. Moreover, the expressed oil, in contrast with palm oil, is free from hydrolytic enzymes (Grindley and Akour, 1955). Sufficient field work has now been accomplished to demonstrate that the high hopes for tung oil (*Aleurites montana* Forst.) have not been realized as it is clear the tree is outside its natural habitat. Further work on tung oil in this area may no longer be justified.

Tobacco culture is suited to many parts of Equatoria and with the

facilities for processing and marketing of the Haggar organization the prospects for development of tobacco as a peasant crop are encouraging.

Lastly there should be an intensification of the production of such fruit crops as *Citrus*, pawpaw, guava, mulberry, avocado pear, custard apple and banana. The fruit crops would be largely for local consumption and would contribute their quota of essential nutrients to the local diet, deficient as it may be in vitamin, protein and edible fats.

THE PRODUCTS OF THE FOREST

Little has been said on the vital importance of forest development and the increasing demands for timber and minor forest produce. The policy of the Forests Department is to build up the forest reserves to the minimum of 15 per cent of the total land surface. Railway sleepers, local housing needs and constructional work as at Nzara must all draw their main requirements of timber and poles from the natural forest. In a country devoid of oil or coal deposits the forest must also play the major part in the supply of power, from charcoal and firewood. Charcoal particularly is required in large amounts by the power station at Nzara for the production of producer gas and firewood for brick kilns, bakeries and domestic use. The heavy demand for charcoal by the E.P.B. mills is supplied mainly by *Cassia siamea* from the Yabua forest reserve on a rotational cutting. Future development may well raise the production of charcoal at Nzara from the present 700 tons per annum to 1800 tons when the mills are in full production. Consideration of such future development leads to the conviction that it would be more profitable to install a wood distillation plant alongside the present power station and to use the wood gas so produced in conjunction with producer gas. Such an industry would not only provide valuable by-products such as creosote, wood spirit, acetic acid, etc. but could meet all the growing demands for charcoal.

Another important commodity for expansion is the bamboo. Areas of bamboo are found growing well in the drier parts of the region but in localities too remote from the consuming centres, where they could be put to a variety of uses. The chief species is *Oxytenanthera abyssinica* Munro but the introduced *Bambusa vulgaris* Schreb. also does well in the wetter areas.

So far as the implementation of these proposals is concerned it seems unlikely that future agricultural development can continue to turn to Government, as in the past, for the large sums of capital required. There is probably little fundamental difference in the development problems of the Sudan from those of other tropical countries even when allowance is made for the fact that such territories may be placed in a more advantageous position. If such countries had been forced to depend on Government funds as well as on Government facilities, there could have been little progress in such regions as the West Indies, the Far East and Australasia. These great territories have been developed mainly by private enterprise on the part of the companies and corporations, large and small, foreign and domestic, with the encouragement and facilities of the territorial Governments concerned. It seems that the time has arrived when the Sudan must think seriously of doing likewise.

The present is a time of difficulty and the south is in a state of flux. Many

plans are in the air but the reality of a southern problem has now been recognized and acknowledged. With confidence restored and a new policy accepted the south may once again find itself looking forward with renewed hope to a future of prosperity and peace. That at least is the hope of all well-wishers of the new republic.

SOME CONCLUSIONS AND PROPOSALS

From a standpoint of agricultural development the southern Sudan is clearly a problem territory. Its geographical position between the tropical rain forest of the Congo and the savannah country to the north constitutes a distinct obstacle to its expansion. It is thus a marginal, as well as an underdeveloped, region which must be self-supporting. Its export produce must be confined to high value crops which produce a profit margin sufficiently high to enable high transport costs to be sustained. The question is by what practical measures can this be achieved ?

The climate and soil conditions of the savannah area are favourable for annual crops and animal husbandry. The wetter zones, in spite of a dry season extending over three months, are capable of producing to a considerable degree tropical crops much needed within the country. At present the pattern of local agriculture is almost wholly one of shifting cultivation and bush fallow. We have seen that there are solid grounds for the view that the cultivation of tree crops is the best form of land use over much of this territory. They should now be built up into the permanent agronomic structure, and developed as part of peasant agriculture, especially in Equatoria, where soil and climate are particularly suitable. It is a matter of debate how much of local native practice can be justifiably retained and informed opinion varies from that of LAVAUDEN (1935), who declares bluntly that the European agriculturist has nothing to learn from the African farmer, to DE SCHLIPPE (1954), who believes that native agriculture can be little improved. As usual the truth lies somewhere between these extremes.

The many advantages of tree crops have already been discussed and in our opinion offer the best permanent solution to the major problem of maintaining soil fertility. Admittedly there are many difficulties to be overcome but whether peasant or plantation agriculture is considered few of these problems are insuperable. To meet the changing circumstances today the research policy must show more boldness and initiative. As investigators we are not justified in allowing our thinking to be too circumscribed by purely native systems of agriculture. Africa is changing rapidly and the tribes are already looking to new horizons. Perhaps by modifying our outlook it may be possible to accomplish in the south what has already been done in neighbouring territories with closely similar backgrounds. To some, the idea of tree crops may come as a new, perhaps revolutionary, concept in present agronomic practice for this region. But this should not hold us back if such a project offers a reasonable solution to the present impasse (WILLIMOTT, 1954).

One of the tantalizing aspects of agriculture in the south is that almost any tropical or sub-tropical crop will grow, but never quite at the level to influence economic markets. Nevertheless, it is in the field of tropical products that development is most urgently needed and would be of most benefit

to the Sudan. This is brought out by a scrutiny of the value of some principal food products, all comprising tropical produce, imported into the country. The data available are both revealing and challenging (Sudan Government, Dept of Economics, 1955). Taking a five-year average, imports of the following commodities were of the order indicated in Egyptian pounds:

Import	*Sugar*	*Tea*	*Coffee*	*Tobacco*	*Total*
£E million	4·0	2·3	2·0	0·8	9·1

and lesser, though not negligible, amounts for fruit juices. These details represent about 18 per cent of the total annual imports into the Sudan and the tendency is for these imports to increase. Even excluding wheat flour, which could be produced in Northern Province, import costs amount in all to a disturbing total of about ten million Egyptian pounds per annum. When much of these foodstuffs could be produced in the south, it seems difficult to justify the continuance of expenditure on this level for a comparatively poor country. This stresses the importance of adopting a policy of economic self-sufficiency within the country, so that the products of North and South become complementary.

The most promising crops for development are sugar, coffee, tea, edible oils, tobacco, with some further expansion of tropical fruits. In this way the country could be made virtually self-supporting so far as the staple foodstuffs and other necessary commodities are concerned, on a system of internal agricultural economy. There would remain the principal revenue earned by the main cash crop, cotton, from the Gezira and the north. It is significant that, as a result of his surveys in the south, Myers (1937–42) came to the conclusion that if export crops increased but slowly there would be no insuperable obstacle to the creation within Equatoria of an economy independent of world prices whereby the indigenous peoples could exchange their complementary products to the benefit of all. The present proposal is simply a logical extension of this principle of self-sufficiency applied generally for the benefit of the whole country.

Figure 1 is a sketch map of the Sudan with the broad-leafed woodland and forest area indicated, together with the principal rivers and place names.

SUMMARY

(*1*) A land use survey of Equatoria revealed that less than 2 per cent of the land area was cultivated annually, although 87 per cent is potentially workable.

(*2*) In the southern Sudan shifting cultivation and annual burning have caused, and are still causing, an overall decline in soil fertility while the climax vegetation is being destroyed over large areas. Such destruction increases rainfall losses from evaporation and surface run-off, so that rainfall becomes progressively less effective.

(*3*) Annual burning reduces the soil fertility by destroying soil structure and microflora, while valuable reserves of plant nutrients are lost as ash by wind, leaching and erosion.

(*4*) Soil fertility can be regenerated most easily by encouraging a natural

tree cover to develop on degraded areas. Forest regeneration can proceed readily on these low-nutrient soils once burning is prohibited.

(*5*) Fruit tree crops are now a distinguishing feature of Equatoria province west of the Nile. It is considered that an expansion of other economic tree crops is feasible and should be undertaken in any future development plan.

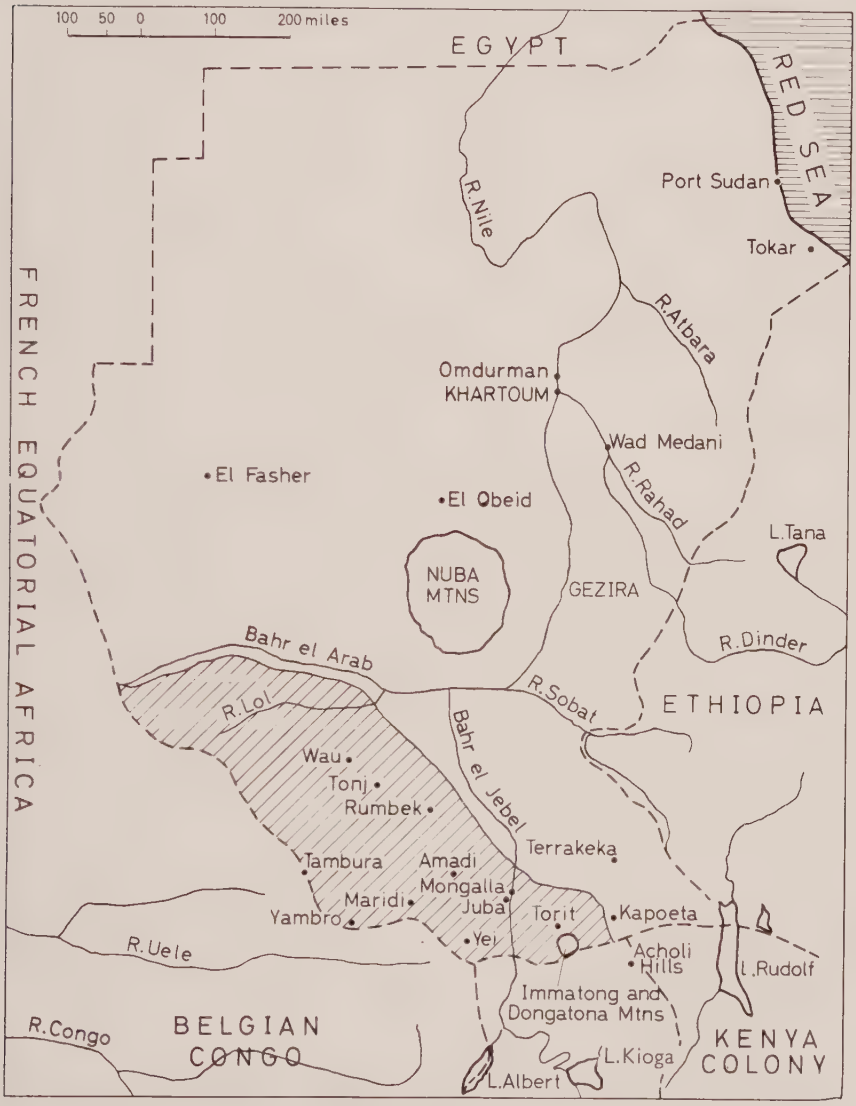

Figure 1. Broad-leafed woodland and forest area of Sudan shown hatched

(*6*) Reserves of soil organic matter and nitrogen are lost when forest is cleared, but losses of fertility may be minimized by the use of suitable cover crops, by mulching, and by correct crop rotation. Organic manures

such as compost and bat guano are of great potential value and their widespread use is recommended. The fate of organic matter in tropical soils requires detailed investigation.

(*7*) A method devised by Hall for utilizing fire-protected bush for compost production, and food and cash cropping is described. Food and cash crops grown in trenches full of compost showed substantial yield increases.

(*8*) Sugar, coffee, tea, palm oil, tobacco and tropical fruits could all be grown in southern Sudan, while bamboo, hardwood charcoal and other forest products could be developed more fully.

(*9*) It is considered that although the economics of artificial fertilizer application preclude their use at present, it is essential for the research worker first to determine the needs of the soil and whether there is any significant reward in crop yield from their use. The importance of this conclusion was recognized in the agricultural research programme at Yambio.

(*10*) Land utilization by the growth of perennial crops incorporated in existing agricultural systems in the south would reduce the level of imports into the country as a whole. The Sudan could become virtually self-sufficient in staple foodstuffs and essential commodities if the internal agricultural economy were changed. Progress in this field would be of lasting benefit and is urgently required.

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Soil Conservation at Mokwa, Northern Nigeria

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HISTORY AND NECESSITY FOR SOIL CONSERVATION

When the Niger Agricultural Project was first started in 1949, the farm area was cleared in rectangular blocks crossed by 'jeep' roads approximately 560 yards apart. The areas between these roads were further subdivided into 24-acre blocks separated by windbreaks varying in width from 30 to 70 yards. Ploughing and ridging operations were generally carried out parallel to the longest side.

When these cultivations ran up and down the hill the water washed down the ridges, collected on the jeep road and broke through another field and so on down the full length of the cleared area which was sometimes as far as two and a half miles. At the bottom of one particular slope a gully six ft wide and three ft deep had formed after only two seasons' cultivation.

The average annual rainfall taken over three years is 41·75 in. with a dry season from the beginning of November until the end of March. The heaviest storms usually occur at the beginning and end of the rains. This year a recording rain-gauge was installed for the first time and intensities of 1·5 in. in 0·5 h and 1·0 in. in 0·25 h were measured.

The soil was originally classified under the Kulfe series. Generally the first two feet vary from sand to a sandy loam and below two feet the soil is a uniform medium loam. Small isolated patches of clay have been recorded and in several places there are outcrops of laterite rock. Most of the land is free draining and there are only a few small isolated depressions where waterlogging occurs. On drying out the soil 'caps' very easily and forms an impermeable skin which causes a high percentage of run-off. Over most of the farm gently undulating slopes of 1 to 3 per cent predominate, although sometimes these slopes are up to three miles long.

In 1954 when the Agricultural Department took over the scheme it was decided that, if mechanical cultivation was to be practised at Mokwa, then soil conservation must be taken in hand. At the very beginning one side of the Pamnini valley was treated as an emergency measure by putting up bunds on the contour at approximately 50 yard horizontal intervals.

GENERAL DESIGN

In evolving a general design the set-up of the scheme as a whole had to be considered. Since it is basically a settlement scheme where the land is cultivated on 'contract' by the Agricultural Department it was essential that the new fields should be laid out so that the farms could be easily divided

amongst the settlers and acreages assessed for the purpose of raising charges. It was also important that the fields were of an economical size for mechanical cultivation.

The lay-out consists of interception type terraces on a variable grade draining from access roads into grassed waterways. Above and below each terrace is a cultivated strip 150 ft wide separated from the adjoining terrace and its cultivated strips by a grass strip of variable width. This grass strip is essential to take up any unevenness in the contours and is laid out with a minimum width of 30 ft so that, should it ever become necessary, an intermediate terrace could be constructed. For simplicity a standard grade and shape of terrace was constructed and employed over the whole area.

TERRACE DESIGN

Distance between terraces

Using the formula

$$\text{Vertical interval} = \tfrac{1}{2}(\%\ \text{slope} + 6\ \text{ft})$$

and considering a general slope of $2\frac{1}{2}$ per cent

$$V.I. = 4{\cdot}6\ \text{ft};\quad H.I. = 55\ \text{yards}.$$

Thus it was decided to have cultivated strips 50 yards wide, this being a convenient width for calculating acreage (100 yards of terrace with a 50 yard cultivated strip=approximately 1 acre) and also within the limits calculated.

Length of terraces

Not greater than 1800 ft: wherever possible terraces of 1500 ft length are laid out, as this makes for more economical use of tractors. Terraces longer than 1800 ft cannot be considered because of the excessive flow of water.

Choice of constants

Since no details are available for Nigerian conditions, constants had to be chosen arbitrarily from such literature as was available (CORMACK, R.M.M. 1951 'The mechanical protection of arable land.' *Rhod. agric. J.* **48,** 135).

(*a*) Maximum length of terrace 1800 ft

(*b*) Width of cultivated strip 150 ft

(*c*) Duration of precipitation to be catered for on areas of less than 10 acres: 25–30 min

(*d*) Rainfall intensity: $I=4$ in./h for 30 min; $I=3$ in./h for 60 min.

These data were taken from the means of rainfall intensity diagrams for Ikeja (Lagos) and Kano which surprisingly enough were remarkably similar. These were the only data available at the time.

(*e*) Maximum permissible velocity: For grassed terraces $V=6$ ft/sec
For bare soil $V=1{\cdot}5$ ft/sec

(*f*) Roughness coefficient: For grassed terraces $N=0{\cdot}03$
For bare soil $N=0{\cdot}0225$

(*g*) Run-off coefficient: $C=0{\cdot}60$

Values of Q

The flow is Q cusecs for various points of the terrace, where $Q = C \times I \times A$ and A = area protected.

At 300 ft	$Q = 2{\cdot}5$ cusecs	At 1 200 ft	$Q = 10{\cdot}0$ cusecs
600 ft	$= 5{\cdot}0$ cusecs	1 500 ft	$= 12{\cdot}5$ cusecs
900 ft	$= 7{\cdot}5$ cusecs	1 800 ft	$= 15{\cdot}0$ cusecs

Calculation of theoretical velocities

Considering Manning's formula for the flow in an open channel

$$V = (1{\cdot}486/N)\ R^{\frac{2}{3}} \times S^{\frac{1}{2}}$$

where N = roughness coefficient, R = hydraulic radius = (cross sectional area)/(wetted perimeter) and S = slope expressed as a percentage.

For a grassed channel 9 in. deep with a bottom width of 7 ft and side slopes of 3 to 1 the theoretical velocities at different lengths, where $A = 7$ ft^2 and $R = 0{\cdot}6$, are as shown in *Table 1*.

Table 1

Length (ft)	*Slope (%)*	*Q (cusecs)*	*Min. permissible velocity to prevent overtopping*	*Theoretical velocity when N=0·03*
300	0·1	2·5	0·61	1·0
600	0·1	5·0	0·71	1·1
900	0·1	7·5	1·1	1·6
1 200	0·2	10·0	1·43	1·9
1 500	0·3	12·5	1·8	2·3
1 800	0·4	15·0	2·1	2·7

Thus with the grades suggested above the theoretical velocities are well within the limit of 6 ft/sec which was considered a necessity since the provision of suitable grasses for the terraces and watercourses is one of the big difficulties of this system.

The final design of the terrace is as follows:

Variable grade	0– 900 ft	0·1 ft fall per 100 ft
	900–1 200 ft	0·2 ft fall per 100 ft
	1 200–1 500 ft	0·3 ft fall per 100 ft
	1 500–1 800 ft	0·4 ft fall per 100 ft

Terrace cross section:

WATERCOURSES

As far as possible natural drainage ways are utilized but these are not very common on the farm area. In consequence watercourses are laid out so that the cross section is as level as possible and in some cases banks will have to be constructed in order to retain the water. On some of the earlier watercourses efforts were made to shape them, but this presents considerable

difficulties and leads to the possibility of gully formation down the centre. The latest watercourses are marked out and cultivated with a Marden Duplex Brush Cutter in order to knock down light growth and attempt to level the area.

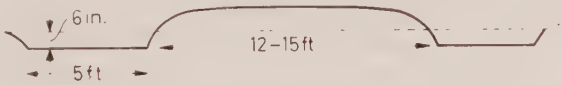
In general it is assumed that a watercourse is draining terraces 1 500 ft long and approximately 300 ft apart which enter from both sides. In such cases the watercourse starts with a width of 75 ft and increases in width by 30 ft for every 1 000 ft length up to a maximum width of 300 ft. In cases where the area drained is less, the width of the watercourse is adjusted accordingly.

TERRACE OUTLETS

These are made in the shape of a fish-tail so as to spread the water evenly over the watercourse. The terrace banks are turned downhill about 30° and so constructed in length that each terrace does not dispose of its water into the same part of the watercourse. In fact for simplicity all terrace outlets are made the same length so that the top terraces disperse into the centre of the watercourse and the lower ones enter the sides of the watercourse.

ROADS

As far as possible these are sited along the high ground but otherwise they are placed midway between the watercourses. They are constructed 12 to 15 ft wide with flat drains 5 ft wide and 6 in. deep on either side. Where land has been terraced these drains will empty either into the terrace channels or into the top half of the intermediate grass strips. In other areas side drains are cut at approximately 3 ft vertical intervals.



CONSTRUCTION

The sequence of operations is as follows:

(*a*) Survey watercourses and mark boundaries. This is probably the slowest part of the whole operation since much of the work has to be done when the grass is high, and before surveying can be carried out the grass has to be knocked down using a 'knocking bar' made of old railway lines, etc.

(*b*) Clear watercourses and level with Marden Duplex Brush Cutter. This machine, pulled behind a New Fordson County tractor, has proved very useful since it allows the tractor to travel up and down and leaves small ridges across the width of the watercourses.

(*c*) Mark in the roads and clear the bush. The roads are stumped by hand and levelled roughly with a disc harrow.

(*d*) Peg out the top terrace on variable grade at 100 ft intervals.

(*e*) Level rough line by discing.

(*f*) Peg at 50 ft intervals.

(*g*) Re-align.

(*h*) Plough line parallel to terrace line 170 ft above peg line to mark edge of 150 ft ploughed strip. This line is placed at 170 ft to allow 20 ft for the width of part of the terrace.

(*i*) Plough line parallel to terrace line 160 ft below peg line to mark edge of 150 ft ploughed strip. The extra 10 ft is allowed for the width of the terrace as in (*h*).

Figure 1. Knocking down grass before surveying

Figure 2. Sowing 'kyasuwa' grass (pennisetum) *on a watercourse*

(*i*) Plough to the peg line with five furrow disc plough. Ploughing two rounds, and then turning one, run out so as to leave finish in position of terrace channel and ridge or back in position of bund.

(*k*) Grade terrace using Adams Leaning Grader and New Fordson County

tractor. About eight rounds are usually required depending on the hardness of the ground.

(*l*) Peg correct grade in the terrace channel at 50 ft intervals.

(*m*) Level to the pegs using terracer blade.

(*n*) After all terraces along one road have been completed then construct roads with Adams Grader.

Figure 3. Terrace being checked after construction

Figure 4. Ridging a terraced field, using a Massey-Harris seeder unit mounted on Ferguson ridger

(*o*) Finish side drains from road, using earth scoop and terracer blade.

For the purpose of terrace construction, the following has been found to make a satisfactory team, and under good conditions they are capable of surveying and constructing one terrace of 1500 ft per day:

1 Surveyor with 3 labourers
5 Tractor drivers
1 Crawler tractor using disc plough and harrow
1 Crawler tractor with grader
2 Ferguson tractors.

MAINTENANCE

After two years very little repair work has had to be done. Whenever possible the watercourses are kept mown and in places where the ground is too rough for a mower the brush cutter has been used. So far no cases of excessive silting up nor of erosion have occurred in the terraces. Two watercourses were eroded down the centre and these had to be treated down their entire length with basketwork check dams. An attempt had been made to shape one of the watercourses and an open furrow was left down the centre. On the other watercourse erosion took place because the terraces were constructed before sufficient grass cover had been established.

GRASS COVER

It has not so far been possible to find a grass which is suitable for the watercourses and terraces. Trials are being carried out at Mokwa on different grasses and in the meantime seeds of *Pennisetum* species which occur naturally in large quantities on the project are collected. The majority of these species are annuals but they establish themselves very quickly from seed and by allowing natural regeneration to take place considerable grass cover is obtained.

GENERAL OBSERVATIONS

The system has worked well and the settlers have certainly been impressed by the results. In approximately two years about 2000 acres have been conserved at a cost of £7–8 per acre. A considerable proportion of the cost of the work consists of tractor expenses used in knocking down grass to permit surveying to be carried out. A clearer picture of the costs will emerge when work has been completed on the first block of 6000 acres; this should be during 1958.

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Post-fertilization Seed and Ovary Development in Passiflora edulis *Sims*

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Many problems have arisen in conjunction with fruit formation and juice yield in *Passiflora edulis* forma *flavicarpa* (yellow-fruited passion fruit). The occurrence of seedless fruit of normal external appearance, noted by Masters (1871), is one of these problems. The amount of juice produced by a fruit is largely dependent on the number of seeds developed. Thus, a seedless or nearly seedless fruit (designated by farmers in Hawaii as ' hollow ') produces only negligible amounts of juice. A second problem involves the condition in plants called self-incompatibility or self-sterility. The term self-sterility has a precedence but self-incompatibility, originated by Stout (1917), is in more general usage today. Bateman (1952) defined self-incompatibility in the following way:' The primary function of self-incompatibility is the avoidance of self-fertilization. It differs from all other mechanisms such as protandry, protogyny, monoecy . . . in that while all the rest act by interposing some mechanical barrier to self-pollination, self-incompatibility acts at a later stage . . .'. Throughout this paper the term self-incompatibility will be used as defined by Bateman.

It has been reported that *P. edulis* Sims is ' self-sterile ' (Masters, 1871). Preliminary studies conducted at the Hawaii Agricultural Experiment Station seemed to indicate that forma *flavicarpa* also shows self-incompatibility (Akamine *et al.*, 1954). Apparently only one investigation of self-incompatibility has been reported in any *Passiflora* species (Munro, 1868); Munro's work was very brief and did not include *P. edulis*.

In 1923 *Passiflora edulis* forma *flavicarpa* Degener was introduced into the Hawaiian Islands by the late E. N. Reasoner of Oneco, Florida, with seed from Australia. Since that time there has been a growing interest in the development of the fruit as a commercial crop in the Territory of Hawaii. Other varieties have been tried but the forma *flavicarpa* which is grown at lower more accessible altitudes in Hawaii has proved more valuable (Akamine *et al.*, 1954).

The plant is a woody perennial vine belonging to the family Passifloraceae which is closely related to the Caricaceae (Killip, 1938). The flowers are hypogynous, choripetalous, with five stamens, a tripartite style, and two series of corona filaments with dark purple bases (Killip, 1938). This variety is distinguished from *P. edulis* Sims largely on the basis of having brown rather than black seeds, yellow pericarp rather than purple, and partially nocturnal flowering rather than being strictly diurnal (Storey, 1950). In addition Degener (1946) also distinguishes *Passiflora edulis*

forma *flavicarpa* from *P. edulis* by the presence of ' two marginal glands on the outer fourth [portion] of the three sepals ' in *flavicarpa*.

PURPOSE AND SCOPE

The purpose of this investigation was to study the two problems; hollow fruit development, and self-incompatibility, and concurrently to initiate an investigation into the embryology of *P. edulis* forma *flavicarpa* [embryology in the broad sense as defined by MAHESWARI (1950) to include endosperm development]. Before hollow fruit formation could be studied a norm had to be established for a standard of comparison, thus the seed and ovary development of normal fruit had to be ascertained. The investigation was limited in this respect to a brief survey of the fertilization phenomena, the ovule structure, and the post-fertilization phenomena with emphasis on embryo, endosperm and seed development. Mega- and micro-sporogenesis and mega- and micro-gametogenesis were not included in this investigation. It is hoped that this study will help to lay the groundwork for future research; and to bring up to date and organize some of the literature concerned with *Passiflora*.

REVIEW OF THE LITERATURE

Although considerable work has been done on the cultural aspects of this species such as trellising, pruning, fertilizing, harvesting, etc. (e.g. RICE, 1928; BARNES, 1934; POPE, 1935; BARNES and WILLIS, 1940; MELVILLE, 1952), there is scant information on the anatomy and cytology of any of the members of the Passifloraceae. MASTERS's (1871) comprehensive work was for many years the only study dealing with the Passifloraceae. He described in some detail the morphology of many of the genera of this family. KILLIP (1938) published a taxonomic revision of the American Passifloraceae which includes 355 species of *Passiflora* and ten species of other genera. Several other accounts of a less extensive nature are available. SCHLEIDEN (1842) included a brief description of *Passiflora* (spp.) ovary development in his textbook. MUNRO (1868) reported on some experimental hand pollinations carried out on a few species of this family. COOK (1909) reports abnormal pollen tubes in some embryo-sacs of *P. adenophyla* Mast. (renamed *P. subpeltata* Ortega by KILLIP, 1938). KRATZER (1916) described the embryo and seed development in three species very briefly. PURI (1947) has published a detailed account of the floral anatomy in the Passifloraceae. STOREY made chromosome counts on 19 species and varieties of *Passiflora* in Hawaii (1937), and discusses the possible genetic origin of the forma *flavicarpa* (1950).

MATERIALS AND METHODS

Flowers and fruits of *P. edulis* f. *flavicarpa* were collected from vines representing many different clones at the Waimanalo Experimental Farm on Oahu and at the ' Mid-Pacific ' area in Manoa Valley, Oahu, during July, August and September of 1955. Pistils were self- and cross-pollinated. The flowers and/or the ovaries were then periodically collected, measured, killed and fixed, sectioned, and stained for the study of fertilization, pollen tube growth, ovary and ovule development.

Pipe cleaners used to apply the pollen were discarded after each individual pollination and flowers were covered with two-pound paper bags in order to insure against contamination by foreign pollen. Flowers or fruits were collected 1 to 10 inclusive, 13, 20, 27, 33, 48, and one fruit 60 days following pollination. The self-pollinated flowers were collected only up to ten days following pollination because these flowers consistently dropped at least by the tenth day after pollination. Often these dehisced flowers could be collected only because they were still within the bags which were fastened to the vine by means of paper clips. One hundred flowers were self-pollinated in three different ways. In 50 flowers the stigmas received pollen from the same flower. In 30 flowers the stigmas of a particular flower were dusted with pollen from a different flower occurring on the same vine. Twenty flowers were merely bagged prior to opening, no effort being made to apply pollen manually. The 200 cross-pollinations consisted of pollinating flowers from different vines. In addition, 26 flowers were not covered with bags but were merely tagged in order to estimate the percentage of set in natural field conditions.

Because there were usually only 20 to 50 flowers opening on any one day it was necessary to carry out numerous successive pollinations. Usually there were only enough flowers opening on a given day for one or possibly two subsequent collections. For example, on a given day 16 flowers were collected from pollinations made three days previously. On the same day 32 flowers were pollinated for the fourth and fifth day collections, etc.

This method introduced a variable, that is the environment was not the same during the initial period of development of each fruit represented in the total collection. It would have been more desirable to have performed all the pollinations for the entire collection during a single day. As this was not possible replicates were made in order to achieve a more accurate estimate of seed and fruit growth. For example, the five-day run was repeated at different times throughout the season.

As a further check on pollination, flowers were cross- and self-pollinated, excised at the pedicel and placed in water and isolated in the laboratory, thus obviating bagging. They were kept in the laboratory in this manner 24 to 48 hours. Temporary mounts were then made from hand-sliced sections of the stigmas and styles in order to determine pollen germination and pollen tube growth.

Plant materials collected in the field were killed and fixed in Crafs III, dehydrated in an ethanol xylene series, imbedded in 56° to 58°C Tissue Mat, and sectioned at 10 to 15 microns. Several staining schedules were used, the most successful being Foster's Tannic Acid–Ferric Chloride counterstained with Safranin (Johansen, 1940), and Haematoxylin and Safranin (Boke, 1939). In addition to processing paraffin material, stigmas and ovaries were cleared in 80 per cent lactic acid to facilitate observations of pollen tube growth (Simpson, 1929).

Field studies included collections of mature normal and hollow fruit during 1954–55 and counts of the ovules and seeds contained in 330 of these fruit. Counts were also made of normal and hollow fruit produced by 48 plants growing at Waimanalo. Seven vines, arbitrarily selected from among the 48, were inspected once a week for 16 weeks during a period from July

1955 to January 1956. In addition fruit checks of all 48 vines were conducted for six consecutive weeks during November and December, plus one week in January.

All microscopic measurements were made with either a Spencer dissecting microscope or a Spencer binocular compound microscope. Gross measurements were made with the use of callipers and millimetre rule. Macrophotographs were taken with an Exacta Automatic VX. Microphotographs were taken with a Silge and Kuhne Orthophot.

OBSERVATIONS

Field studies

Lack of available information relative to a correlation between seed and ovary development necessitated work along these lines. There were found to be an average of 300 ovules produced per fruit based on counts of 330 fruits taken from vines growing at the Waimanalo Experimental Farm. The average normal fruit contained approximately 180 (60 per cent) fully developed seeds. The mean transverse diameter of a mature ovary was 54 ± 7 mm. The length of the mature seed was 7 mm regardless of the ovary size.

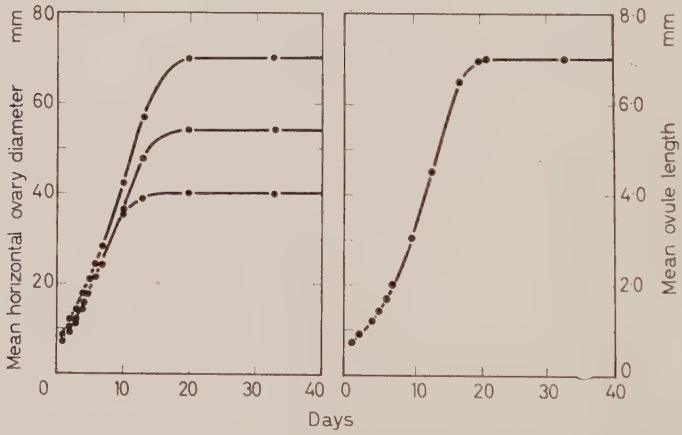

Figure 1. Growth curves of the ovaries and ovules of P. edulis *f.* flavicarpa *showing the mean transverse (horizontal) diameters of three sizes of fruits of terminal sizes 39, 54 and 70 mm. Each dot represents the mean determined from measurements of from six to fifteen randomly selected fruits. Each dot in the ovule growth curve represents the means of measurements of the lengths of ten ovules from each of at least six different fruits*

The growth curves in *Figure 1* indicate that the maximum ovary diameter and seed length is attained approximately 20 days after pollination. The aril (pulp sac) reaches its maximum length, 15 mm, approximately 27 days after pollination. From *c.* 27 days to *c.* 35 days following pollination the amount of pulp per seed increased concomitant with decrease in the thickness of the ovary wall.

Fruits can be found containing any number of mature seeds from 0 to 320. Because of this variability arbitrary limits were established for defining hollow fruit. The most satisfactory method was to determine the percentage of mature seeds in a fruit based on the total number of fertilized

and unfertilized ovules. From experience the various fruits containing 0 to 30 per cent mature seeds were considered hollow, those containing 40 per cent or more mature seeds were considered normal. The fruits containing 30 to 40 per cent mature seeds were labelled partially hollow, not being considered to belong to either category.

Figure 2 shows that the proportion of hollow fruit produced throughout the season is relatively constant, varying only from 6 to 7 per cent. When the field yield of normal fruit was high, as for example during July and October of 1955, the field yield of hollow fruit was also high. The trend of the curve for hollow fruit yield during the six months period approximated the trend of the curve of normal fruit yield for the same period (*Figure 2*).

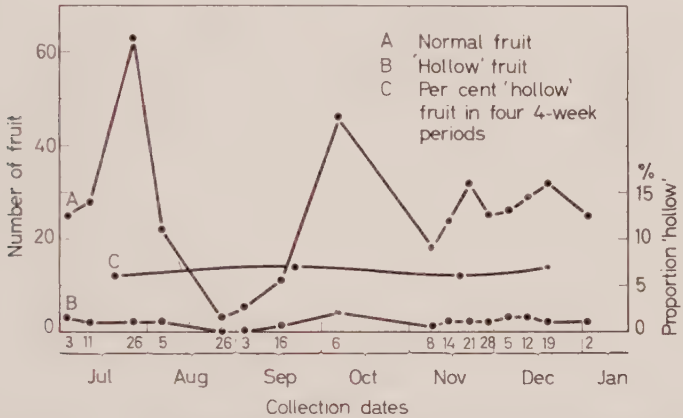

Figure 2. Total fruit yield from seven vines growing at Waimanalo during a period from July 1955 to January 1956

Many of the normal fruit were noted to possess large scars resulting from the stinging of fruit flies. It has been reported that *Dacus cucurbitae* Coquillett and *D. dorsalis* Handel occurring at Waimanalo are responsible for these scars (NISHIDA, 1954). In the mature fruits which were examined the stinging seems to have little or no effect on the formation of seed (*Figure 3*). However, it has been reported that ovaries if stung when very young drop off (NISHIDA, 1954). In this investigation it was noted that ovaries that were stung withered and dropped off in five to ten days only if stinging occurred before they were *c.* 35 mm in transverse diameter. Thus, a fruit seems to be vulnerable to stinging during the interval of approximately 1 to 10 days following flowering. An ovary stung during this interval of time abscinds. If stinging occurs more than 11 days after flowering it has little effect other than to produce a scar in the pericarp.

Certain vines growing at Waimanalo consistently gave high hollow fruit yields (*Table 1*). Vine number 34 which was inspected once a week for 16 different weeks between July and January showed a yield of 14 per cent hollow fruit. Vine number 21 examined during the same interval of time had no hollow fruit. The average proportion of hollow fruit for all 48 vines was 6·5 per cent (*Table 1*).

Figure 3. Mature normal fruit with scar (S) in pericarp as a result of fruit fly's stinging

An examination of the results of certain cross-pollinations reveals that possibly some crosses produce more hollow fruit than others. It was planned to repeat these crosses during the spring and summer of 1956 but unfortunately the vines were torn up and disposed of before this could be accomplished. The number of cross-pollinations in the aforementioned experiment

Table 1. Hollow fruit produced by individual vines at Waimanalo

Vine	*Total fruit*	*Hollow fruit*	*Per cent hollow*	*Vine*	*Total fruit*	*Hollow fruit*	*Per cent hollow*
1*	29	2	6	25	33	1	3
2	34	4	16	26	19	2	10
3	15	0	0	27	21	3	14
4	14	1	7	28	13	0	0
5	27	1	3	29	22	1	4
6*	76	4	5	30	22	1	4
7	20	2	10	31	55	0	0
8	21	0	0	32	16	0	0
9	22	2	9	33	21	0	0
10	15	1	6	34*	114	17	14
11	26	1	3	35	32	3	9
12	57	2	3	36	21	2	9
13*	75	6	8	37	19	4	21
14	32	3	9	38	21	5	23
15	37	1	2	39	15	1	6
16	34	3	8	40	13	2	15
17	17	0	0	41	9	0	0
18	19	1	5	42*	30	3	10
19	48	3	6	43	12	0	0
20	21	1	4	44	15	0	0
21*	53	0	0	45	30	0	0
22	30	1	3	46	34	0	0
23	28	1	3	47*	42	2	4
24	11	0	0	48	15	1	6
			Total	48	1345	88	

Average proportion of hollow fruit from total number of fruit = 6·5 per cent.
* These seven vines were inspected once a week for 16 weeks, the remainder were checked once a week for seven weeks. Remarks concerning individual vines will be restricted to the vines which were inspected during the longer period.

is too small to be statistically meaningful. However, the indication exists that there is some type of genetical basis for hollow fruit formation.

Pollen morphology and pollination

HANSGIRG (1897) in a few lines described the pollen in the family Passifloraceae, as being spherical, from 25 to 100 microns in diameter, perishing in water, and with a net-like sculptured extine. Results of the present study showed that the pollen grains of *flavicarpa* are about 80 microns in diameter. They have a reticulately sculptured extine which is interrupted by three circular channels. The pollen grain germinates with the tube pushing through a portion of one channel and forcing a third of the pollen grain's extine to bend out like a hinged cap (*Figure 4*).

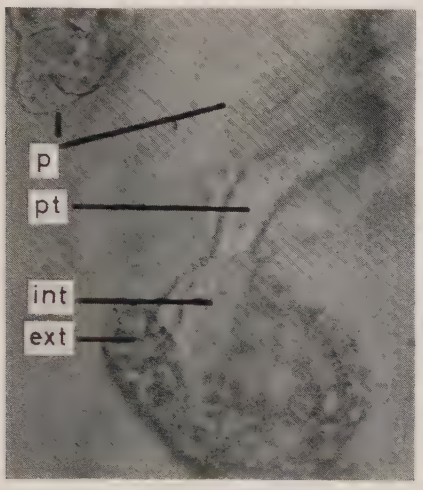

Figure 4. Pollen grain with pollen tube in papillae of stigma. ext, *extine;* int, *intine;* p, *papillae;* pt, *pollen tube.* ×*370*

Figure 5. Recently opened flower and Carpenter bee. a, *anther;* b, Xylocopa varipuncta

Attempts were made to germinate the pollen grains in distilled water, in tap water, in sucrose solutions of 0·5, 1·0, 5·0, 10·0, 20·0, 30·0, 40·0, 50·0, 60·0, 70·0 and 80·0 per cent. In all solutions the results were similar. A few seconds after the pollen grains are placed in the solutions there exudes from the areas of exposed intine (circular channels) a viscous material which remains visible for less than a minute. Subsequently the remaining contents of the pollen grain erupt out of the grain as a club of fan-shaped exudate which ultimately disintegrates. Using lactose agar medium in van Tiegman cells (BISHOP, 1949) a similar sequence of events took place, also without the germination of any pollen grains. Stigma extracts used alone and in combination with various concentrations of sugar yielded similar negative results. The only successful method for germinating pollen in the laboratory was to pollinate an excised flower. After about five hours, germinating pollen grains could be observed with pollen tubes often entering the stigma papillae.

In whole mounts made from plant material cleared with lactic acid

unidentified granules were noted which were definitely within the pollen tubes. These granules were numerous and highly refractive (*Figure 17*).

In Hawaii pollen is reportedly transferred from flower to flower by means of the Carpenter bee, *Xylocopa varipuncta* Patton (NISHIDA, 1954). In the process of obtaining the nectar situated below the gynophore the bee brushes the anthers and large quantities of pollen fall on its back (*Figure 5*). It is hypothesized that repeated visits to many flowers probably effectuate cross-pollinations. Wind has also been suggested as a possible mode of pollen transfer in *Passiflora* (GIROLAMI, personal communication), although no experiments to test this were undertaken prior to June 1956.

Table 2. Results of hand-performed pollinations and counts of fruit yields in the field

(a) *Self- and cross-pollinations*

	Total flowers	*Fruit set*	*Abscinded flowers*	*Fruit set per cent*	*Abscinded flowers per cent*	*No. of hollow fruit*	*Per cent hollows based on fruit set*	*Per cent hollows based on No. of flowers*
Self-pollinations	100	0	100	0	100	—	—	—
Cross-pollinations	130	44	88	33	67	4	9*	3†

(b) *Fruit yields under natural field conditions*

	Total	*Normal fruit*	*Hollow fruit*	*Per cent hollow fruit based on total No. of fruit*
Mature fruit	1345	1257	88	6·51†

(c) *Fruit set under natural field conditions*

	Total flowers	*Fruit set*	*Abscinded flowers*	*Per cent fruit set*
Tagged, unmanipulated flowers	26	18	8	70

* The discrepancy between the 9 per cent hollow fruit shown in *Table 2a* and the 6·5 per cent hollow fruit shown in *Table 1* and *Table 2b* is discussed in the text.
† The 3 per cent hollow fruit shown in *Table 2a* is not comparable to the 6·5 per cent shown in *Table 2b* because the former is based on the number of flowers and the latter is based on the total number of fruit (see *Table 1*).

One hundred self-pollinations performed at Waimanalo and at the ' Mid-Pacific ' area consistently demonstrated the existence of self-incompatibility. At no time did fruit set or begin to develop from a selfed flower (*Table 2*). The incompatibility manifests itself at the stigma, that is the pollen grains either remain intact or occasionally germinate in which case the pollen tubes never attain a length greater than 80 microns. Since the distance from the stigma papillae to the uppermost ovule is approximately 20 mm these short pollen tubes are totally ineffective for accomplishing fertilization.

The results obtained from the manually performed pollination experiments are shown in *Table 2*. The percentages of set and abscinded fruit resulting from hand pollination are 33 and 67 per cent respectively. Under natural field conditions the percentages of set and abscinded fruit are 70 and 30 per cent respectively. The high rate of abscission in the hand pollination experiments is possibly a consequence of induced abscission resulting from bruising the flower in the process of manipulation, and covering the flower

after pollination, which may raise the relative humidity unfavourably. However, the small number of observations of naturally pollinated flowers precludes any definite conclusion.

The proportion of hollow fruit based on the total number of fruit which occur naturally in the field is 6·5 per cent (*Tables 1* and *2*). No hollow fruit were collected from the tagged, unmanipulated flowers which were not bagged. Hand pollinations yielded 3 per cent hollows based on the total number of flowers. It is to be expected that the percentage of hollows based on the number of flowers would be smaller than that based on total fruit.

Cross-incompatibility is necessarily present in self-incompatible species (BATEMAN, 1952). That is the same combination of *S*-alleles which produces self-incompatibility will sometimes occur in crosses between certain clones. However, not all of the drop (64 per cent) of the cross-pollinated flowers should be ascribed to cross-incompatibility. The high percentage is in part a result of the induced flower abscission mentioned above, and also flower drop which occurs in most plants for various other reasons at present not known.

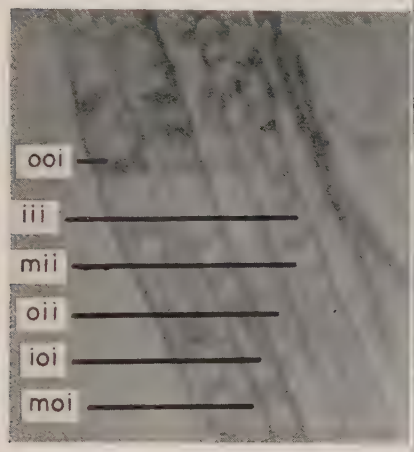

Figure 6. Portion of an ovule four days after pollination. ooi, *outer cell layer of outer integument;* moi, *middle layer of outer integument;* ioi, *inner layer of outer integument;* oii, *outer layer of inner integument;* mii, *middle layer of inner integument;* iii, *inner layer of inner integument*

Figure 7. Longisection of ovule one day after pollination. ar, *aril;* e, *embryo sac;* f, *funiculus;* ii, *inner integument;* oi, *outer integument;* pt, *pollen tube.* × *100*

DEVELOPMENTAL ANATOMY OF THE OVULE

Normal development

At the time of fertilization the anatropous ovule, as seen in median longisection, consists of two three-layered integuments and a nucellus which is usually four to five cells in width, enveloping a large embryo sac which contains at least five nuclei*. The aril is present as a multicellular collar around the funiculus (*Figure 7*).

* The exact number of nuclei present in the ovule at the time of fertilization cannot be stated with certainty. It is suspected that the three antipodals disintegrate early. However, since this investigation was limited to post-fertilization phenomena and because of the usual difficulties encountered (deeply staining material discharged by the pollen tube which obscures the embryo sac nuclei) in observing stages directly following fertilization, the exact configuration of the embryo sac at the time of fertilization was not determined.

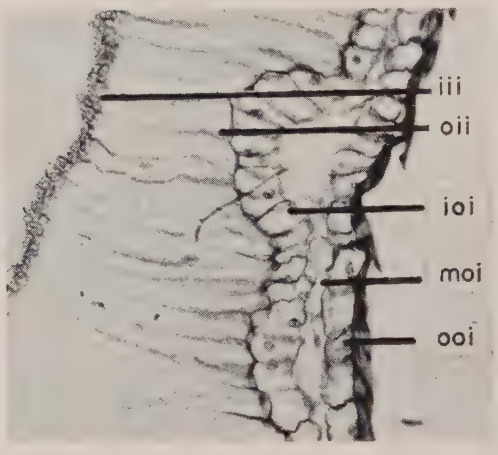

Figure 8. Longisection of integuments of ovule thirteen days after pollination. ooi, *outer cell layer of outer integument;* ioi, *inner layer of outer integument;* iii, *inner layer of inner integument.* × *300*

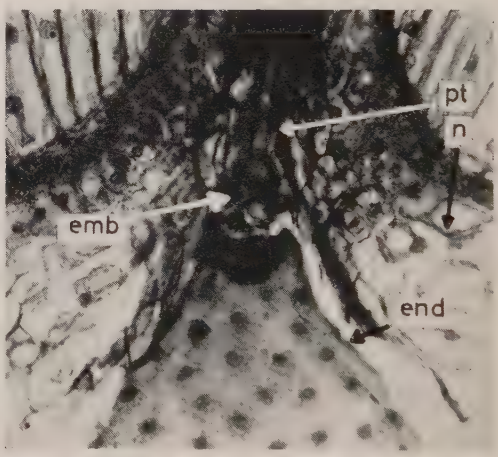

Figure 9. Longisection of micropylar region of an ovule thirteen days after pollination. emb, *embryo;* end, *endosperm nuclei;* pt, *pollen tube in micropyle;* n, *nucellus.* × *300*

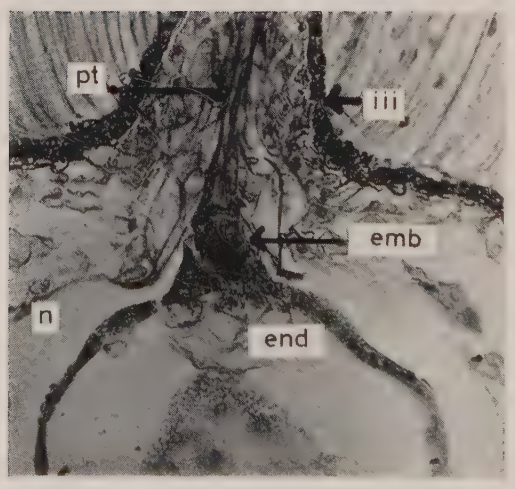

Figure 10. Longisection of an ovule thirteen days after pollination. emb, *embryo;* end, *endosperm nuclei;* iii, *inner cell layer of inner integument;* n, *nucellus;* pt, *pollen tube.* × *330*

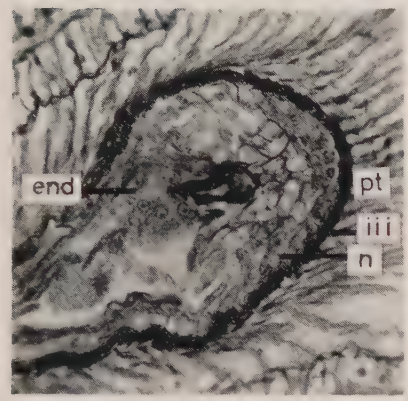

Figure 11. Longisection of portion of an ovule seven days after pollination. end, *endosperm nuclei;* iii, *inner cell layer of inner integument;* n, *nucellus;* pt, *pollen tube.* × *250*

Figure 12. Line drawing of an embryo taken from mature, normal seed. c, *cotyledons;* h, *hypocotyl;* v, *future vascular bundles.* × *18*

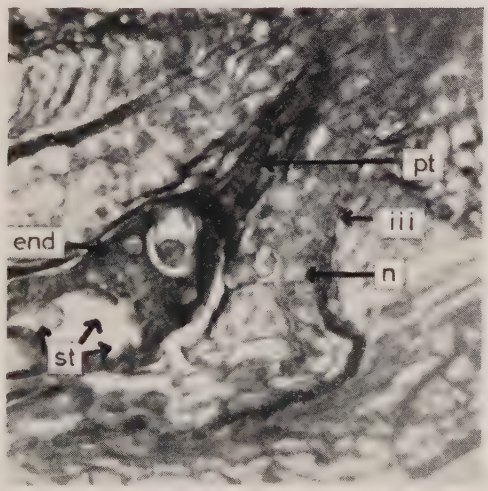

Figure 13. Longisection of micropylar region of an abortive ovule from a mature hollow fruit which contained nine fully mature seeds. end, *endosperm nuclei;* iii, *inner cell layer of inner integument;* n, *nucellus;* pt, *pollen tube;* st, *starch grains.* × *300*

The pollen grains that land on the tips of the individual papillae of the stigma (*Figure 4*) germinate and the pollen tubes continue their growth through the style (' closed type ', HANF, 1935). Within 24 hours after cross-pollination pollen tubes are usually in the vicinity of the micropyle (*Figure 7*).

Following fertilization the cells of the two integuments begin to differentiate. The innermost two cell layers of the inner integument which remain very small become compressed as the outer layer of the inner integument undergoes anticlinal elongation. The elongation of the outer cell layer of the inner integument is very irregular and produces corrugation on the surface of the seed coat (*Figure 8*). Thus the sculpturing visible on the surface of the mature seed is predominantly the result of the irregular growth of this cell layer. The innermost cell layer of the inner integument remains small and highly refractive (iii in *Figures 6* and *8*). This cell layer is present in the mature seed as a thin sheath surrounding the endosperm. The middle layer of the inner integument is much compressed and by 13 days is no longer visible (*Figure 8*). The three cell layers of the outer integument are sloughed off or degenerate before the seed reaches maturity.

Nucellus collapse and absorption begins and occurs concomitantly with endosperm initiation and development (n in *Figures 9* and *10*). Four days after pollination there is still much nucellar tissue present in the ovule. By 10 to 15 days much of the nucellar tissue has disappeared, remnants can be seen around the periphery of the embryo sac (n in *Figures 9* and *10*).

The endosperm which first becomes evident about seven days after pollination (*Figure 11*) becomes very noticeable by 13 days (*Figures 9* and *10*). The endosperm remains coenocytic until about 20 days after pollination. Cytokinesis then occurs simultaneously and uniformly throughout the embryo sac. This is similar to the condition which KRATZER (1916) reports for three *Passiflora* species with which he worked.

Immediately after fertilization the aril begins to develop (*Figure 15*) and eventually forms the mature aril, or pulp sac. Kratzer also found this to be true in *Passiflora suberosa*, *P. trifasciata* and *P. quandrangularis*. He states '. . . *an ausseren Umfang des Funiculus tritt . . . ein Ringwulst auf, die Anlage des Arillus* '. The length of the aril is related to the ovule length, for example at 10 days, ovules from different fruit may be 2·8 or 3·2 mm long. The arils of these ovules are 0·3 and 0·4 mm long respectively. In other words at ten days the length of the aril is 10 to 12 per cent of the length of the ovule. At 13 days (*Figure 16*) the aril is approximately 33 per cent of the ovule length. At 20 days the aril surrounds the seed but does not exceed the length of the seed. By approximately 25 days after pollination the aril reaches its full size, 15 mm in length, extending 6 to 10 mm. beyond the chalazal end of the seed.

No work on embryo development has been reported for the genus *Passiflora* (JOHANSEN, 1950). In the present study, the early stages of embryo development were difficult to follow because of the small size of the embryo and of densely staining material in the embryo sac which obscures the cells. Thirteen days after pollination the embryo consists of six to eight cells (*Figures 9* and *10*). *c.* 30 to 35 days following pollination the embryo reaches mature size and the future vascular system is well defined in the hypocotyl

and cotyledons. The embryo in the mature seed closely resembles the embryo of *Carica papaya* (FOSTER, 1943) (*Figure 12*).

Abnormal development

All the hollow fruit examined showed some development of the ovules. Some of these fruits had only a few seeds with pulp and a normal embryo. Some hollow ones had no fully developed seeds, all being partially developed. A few mature hollows were examined in which all of the ovules had apparently stopped growing four to eight days after pollination. Remnants of pollen tubes could be seen (*Figure 13*) in all the partially developed ovules whose cells had not been dead so long as to have completely collapsed.

The majority of the ovules from hollow fruit that were examined had no visible embryo; however, free endosperm nuclei were very apparent (*Figure 13*). A very few of the fruits contained ovules with no recognizable endosperm but possibly degenerated endosperm cells surrounding the embryo (*Figure 14*). Thus, the effect of the interrelationship between embryo–endosperm–maternal tissue as discussed by BRINK and COOPER (1947) is probably the mechanism instrumental in the formation of hollow fruit.

DISCUSSION

The purpose of the present study was to make a broad survey of the post-fertilization phenomena in *Passiflora edulis* f. *flavicarpa*. Two problems, hollow fruit and self-incompatibility, which apparently have not been considered recently in connection with the genus *Passiflora*, became the focal points for the survey. The methods used in undertaking this investigation were the ones commonly used in an investigation of fruit development. Morphologically and antomically the fruits which developed from hand pollinations were found to be similar to those which developed under natural field conditions. Numerically, the results obtained from the hand pollination experiments are probably not reliable (*Table 2*). There is the ever-present possibility of induced abscission resulting from handling the flower and bagging.

'Hollow' fruit

The number of completely mature seeds differed from fruit to fruit as did also the stage of development attained by the ovules within the mature fruit. For example, a fruit from a collection made in January 1955 contained 140 mature seeds each 7 mm long and 74 partially developed ovules approximately 4 mm long. Another fruit from the same collection contained 150 mature seeds 7 mm in length and 144 partially developed ovules each approximately 2 mm in length. Similarly, STOUT (1936) found in connection with seedless grape, *Vitis vinifera* L., that 'Several types or grades of seedlessness are to be recognized in respect of the extent, the degree, and the time of abortion in the ovules . . .' In the passion fruits examined during the present investigation there was found to be a complete gradation from 0 to more than 90 per cent fully developed seeds. Because there is no definite boundary between hollow and normal fruit, artificial limits were chosen in order to facilitate the work. The fruits containing 30 per cent or less fully developed seeds have been designated as 'hollow' fruit.

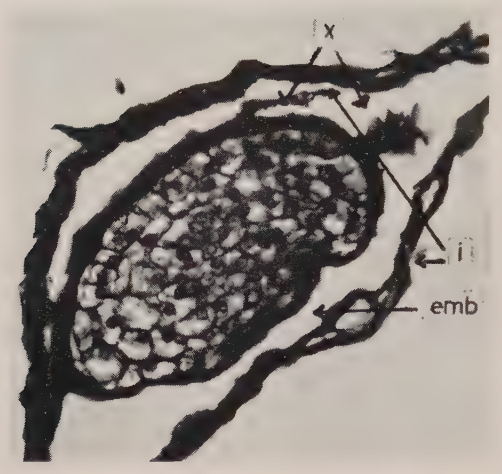

Figure 14. Longisection of a portion of an abortive ovule from a mature hollow fruit. emb, *embryo in cross section;* i, *degenerated cells of integuments;* x, *appears to be degenerated endosperm.* × *220*

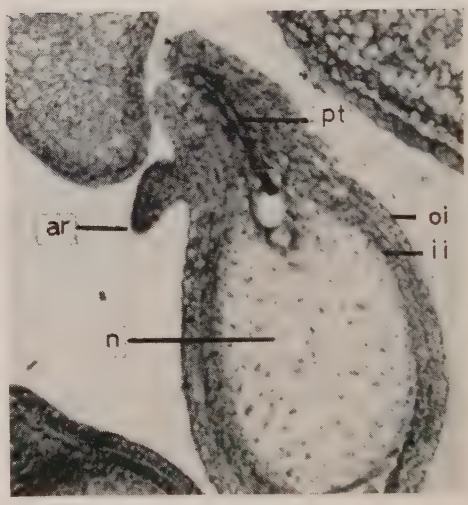

Figure 15. Longisection of an ovule four days after pollination. ar, *portion of aril;* ii, *inner integument;* n, *nucellus;* oi, *outer integument;* pt, *pollen tube within the micropyle.* × *80*

Hollow fruit, as defined in this paper, occurred in various percentages from different vines. The proportion of hollows ranged from 0 to 14 per cent among the vines used in this study (*Table 1*). This variation could be due to physiological conditions existing in the plant. For example, the hollow fruit yield of vine 34 (*Table 1*) when compared with the average of all vines appears high. The vine could have been in a condition such that nutrients were not available in sufficient quantity to produce all normal fruit. In this connection, SMITH (1954 and 1956) mentions the relation between the occurrence of 'pops' in *Arachis hypogaea*, that is empty pods or pods containing shrivelled seeds, and the amount of calcium in the soil. With this in mind an attempt was made in the present investigation to limit the amount of environmental variation by using vines situated in the same field, and subjected to the same conditions of fertilizing, pruning, trellising,

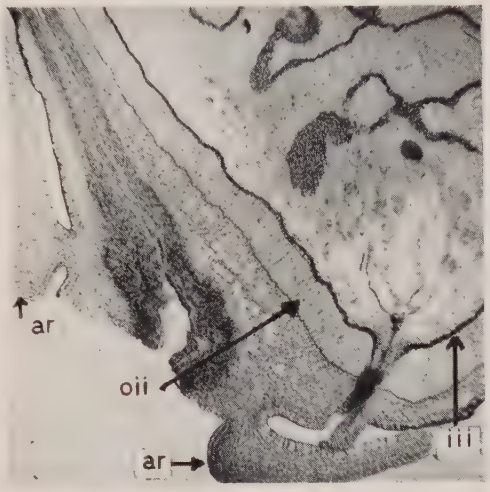

Figure 16. Longisection of an ovule thirteen days after pollination. ar, *portion of aril;* iii, *inner cell layer of inner integument;* oii, *outer cell layer of the inner integument.* × *50*

Figure 17. Whole mount of a portion of an ovule cleared with lactic acid 48 hours after cross-pollination. g, *highly refractive granules;* pt, *pollen tube entering micropyle;* v, *vascular strand.* × *150*

etc. Thus, it is unlikely that physiological conditions such as deficiency in nutrients as mentioned by SMITH (1954 and 1956) are responsible for the individual vine variation in hollow fruit yield.

Evidence supporting the hypothesis that a genetical basis for hollow fruit formation exists, is the lack of seasonal variation in hollow fruit production (*Figure 2*). If environmental conditions were largely responsible for hollow fruit formation then seasonal variation in hollow fruit yield might possibly occur. However, seasonal fluctuations in the percentage of hollow fruit are slight, varying approximately 1 per cent, that is between 6 and 7 per cent (*Figure 2*).

In regard to the sequence in the development of aborted ovules, BRINK and COOPER (1947) emphasize the importance of the endosperm as a mediary tissue between the embryo and maternal tissue. They report that in *Medi-*

cago sativa L. the endosperm apparently controls the development of the embryos and seeds.

In the foregoing it has been suggested that genetical differences are at the basis of hollow fruit formation. However, the incomplete development of some of the ovules which are found in both normal and hollow fruits may also be due to intraplant environmental factors. This is one line of experimentation that should prove valuable.

Further study may necessitate changes in the proposed limits separating normal and hollow fruit. Any delimitation which is based on the percentage of fully developed seeds will necessarily be artificial and subject to revision.

All of the mature hollow fruit that were examined contained at least a few partially or fully developed ovules. The ovules contained endosperm and/or embryo, and a pollen tube was generally visible in the micropyle (*Figure 13*). It is assumed throughout this paper that fertilization has occurred if a pollen tube is present in the micropyle or embryo sac. Often there is no visible evidence that fertilization has taken place because of the difficulties encountered in observing developmental stages following pollination, that is densely staining material discharged by the pollen tube (see footnote, page 49). Although it is possible that these fruits were formed parthenocarpically the author feels that it is much more likely that syngamy has occurred in this case.

Hollow passion fruit may possibly be compared to the seedless Sultana cultivar of *Vitis vinifera* L. in which PEARSON (1932) found a majority of normal fertilized embryo sacs which contained aborted ovules and embryos. STOUT (1936) in discussing the 'several types or grades of seedlessness', lists four possible conditions for the occurrence of the aforementioned seedless grapes: (*1*) faulty megagametophyte and no fertilization, (*2*) fertilization with arrested embryo and endosperm development, (*3*) fertilization with no endosperm or embryo but with a normal mature seed coat, and (*4*) no fertilization, with seed of normal appearance and apogamic embryo. Conditions (*1*) and (*4*) can be discarded as possible explanations for the formation of the hollow fruit under discussion because pollen tubes were present in the micropyles of the ovules within these fruit and fertilization is assumed to have occurred. Moreover the megagametophyte seemed to be normal. Condition (*2*) is probably the type responsible for the abortive seeds in hollow passion fruit. A few seeds of type (*3*) were found both in normal and in hollow fruit.

MUNRO (1868) reports several self-sterile *Passiflora* species, e.g. *P. alata* Dryland. He also found *P. alata* to be 'cross-fertile' when pollinated with pollen from its own progeny. He reports that the following interspecific crosses produced mature ovaries which 'contained no seed': *P. kermissina* Link and Otto × *P. alata*; *P. racemosa* Brot. × *Tasconia mollissima* HBK (renamed *P. mollissima* Bailey by KILLIP, 1938); and *P. caerulea* L. × *P. racemosa*. MUNRO's (1868) results also support the contention that there may be a genetical basis for the formation of hollow fruit.

Self-incompatibility

EAST (1929) interpreted the phenomenon of all 'self-sterile' plants by

applying the *S*-allele system originated by East and Mangelsdorf (1925) as a result of their work with *Nicotiana*. They proposed that there is a series of alleles which control the rate of pollen tube growth. For example, a stigma carrying the alleles S_1 S_2 when pollinated with pollen carrying either an S_1 or S_2 allele results in no fruit set because the pollen tube grows very slowly or not at all or fails to culminate in fertilization when it does reach the micropyle of the ovule. In the *Nicotiana* type of inheritance the female plant when pollinated with pollen from its progeny should produce fruit (Gerstel, 1950) as Munro (1868) reported occurring in *Passiflora alata*. Whether or not the incompatibility exhibited in *P. edulis* f. *flavicarpa* is similar to the *Nicotiana* type of *S*-allele system or similar to a system such as suggested by Gerstel (1950) cannot be concluded at this time. As a result of this investigation it is known that the pollen grains on selfed *flavicarpa* stigmas either do not germinate or occasionally do germinate but the pollen tubes only grow to a length of *c.* 80 microns. The meagre evidence thus far points to the existence of the *Nicotiana* type of *S*-allele inheritance in *Passiflora*. In the forma *flavicarpa* at least, the incompatibility takes effect at the stigma.

SUMMARY

(*1*) Collections and measurements of more than 300 ovaries and fruits yielded the growth curves for seed and ovary of *P. edulis* f. *flavicarpa*.

(*2*) Counts of 1345 fruits which were produced by 48 vines growing at the Waimanalo Experimental Station showed an average of 6·5 per cent hollow fruit produced.

(*3*) Certain vines were located which yielded throughout a six months period a high percentage of hollow fruit. Other vines yielded no hollow fruit during this same period.

(*4*) Anatomical investigations of the ovule showed that the mature seed coat consists largely of the sclerified outer cell layer of the inner integument. The embryo develops slowly at first, and *c.* thirteen days after pollination consists of six to eight cells. The endosperm remains coenocytic until the embryo is many-celled. Pollen tubes could be seen in ovules from mature hollow fruit.

(*5*) Self-incompatibility was manifested without exception in the vines at Waimanalo and the ' Mid-Pacific ' area. The pollen grains on selfed flowers either germinated with pollen tube growth terminating in the vicinity of the stigma papillae or the grains remained intact.

(*6*) Results of several manually performed crosses between specific vines yielded hollow fruit.

(*7*) The indication seems to be that there is some type of genetical basis for the formation of at least some hollow fruit.

ACKNOWLEDGEMENTS

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Figures 3 to *17* are reproduced without reduction.

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A Preliminary Investigation on the Effect of Mosaic Virus on Manihot utilissima *Pohl. in Nigeria*

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Cassava mosaic in East Africa was originally described by Warburg (1894) under the name of *Krauselkrankheit*. Golding (1936*a*) records Jones's original report of the disease in Nigeria in 1926. It was also recorded in the Gold Coast by Dade (1930), and in Sierra Leone by Deighton (1926). At the time of its discovery the disease was reported to be spreading inland from the coast.

Cassava mosaic is spread in the field in two ways, referred to hereafter as primary and secondary infection. Primary infection is brought about by vegetative propagation from infected plants, since the cassava mosaic virus is systemic in its host and is carried over in infected planting material to successive crops. Secondary infection is the transmission of the disease in the field by the Aleurodid *Bemisia nigeriensis* Corb., first demonstrated by Golding (1936*b*).

In Nigeria Golding (1936*a*) records that only three per cent of the cassava crop at Moor Plantation, Ibadan, was infected with cassava mosaic and was able to compare the yields of infected and healthy plants. He showed that primary infection with cassava mosaic virus caused a decrease of 33 per cent in the yield of the variety ' Karagba ' and of 43 per cent in the variety ' Atu '. He further demonstrated that secondary infection with cassava mosaic virus caused little loss of yield in the season in which infection occurred. Similar work was carried out by Muller (1931) in the Belgian Congo, by Tidbury (1937) and by Briant and Johns (1940) in Zanzibar. These workers record losses due to primary infection of 20 per cent, 76 per cent and 95 per cent respectively.

In the present investigation the effect of cassava mosaic virus on the yield, leaf area, petiole and stem weight of a Nigerian cassava variety was examined. The respiration rate and carbohydrate/nitrogen ratio of leaves and the hydrogen cyanide content of tubers from infected and healthy plants were compared.

MATERIALS AND METHODS

Variety and experimental procedure

Symptomless plants of a mosaic-susceptible Nigerian cassava variety No. 56160 were obtained from Ilorin Province in 1956. It was noted that this variety supported an unusually low *Bemisia* population. The locality where this variety was collected has the lowest average yield per acre (3098 lb/acre) of all the Nigerian provinces (Anon., 1951). The yield of this variety is low and typical of this area. Mosaic symptoms on the leaves

of infected plants were not severe and it is considered that this variety shows a high degree of tolerance to mosaic, although it is of inherently low yield. NICHOLS (1949) has recorded similar clones in East Africa and has suggested that in *Manihot utilissima* Pohl. low yield may be closely linked to mosaic resistance.

Three plots of variety 56160 each consisting of 50 cuttings taken from symptomless plants and three similar plots from plants showing mosaic symptoms were established at Moor Plantation on Iwo series soil (VINE *et al.*, 1954) (a sedentary soil formed *in situ* over granite). Tubers were formed after three months in the field and the first pair of plots harvested at four months from planting. It was decided that after eight months, secondary infection in the field could be expected to reduce the number of healthy plants to below that required for a statistical sample. The remaining pairs of plots were therefore harvested six and eight months after planting. The following observations were made on individual plants: fresh weight of roots, stems and petioles, number of leaves and leaf area, the carbohydrate/nitrogen ratio of the leaves and the hydrogen cyanide content of the roots.

Cuttings were taken from all symptomless and diseased plants at the time of harvest and grown in separate insect-proof screen houses. All cuttings from diseased plants showed symptoms of mosaic four weeks after planting, as did some of the plants previously classified as symptomless. Records obtained from these symptomless carriers were discarded, as were data from originally healthy plants which had been subjected to secondary infection in the field. The number of these plants was not sufficient to provide an adequate statistical sample to test the effect of secondary infection upon yield.

Measurement of leaf area

An accurate method of measuring the area of cassava leaves was evolved by taking sunprints of the laminae on 'Ammonax' paper and measuring the area with an 'Allbrit' fixed arm planimeter. It was found that almost identical values for leaf areas could be obtained by direct measurement of the laminae using a glass grid divided into squares 0·36 cm^2 in area. This method was slow and impracticable for the measurement of the area of large samples of leaves. A rapid method for measuring the leaf area of sugar beet on a field scale has been described by WATSON and WATSON (1953) and it was found that this method could be adapted for cassava leaves if a smaller punch was used.

The efficiency of this method was investigated by first measuring the total leaf area of six cassava plants of varying sizes with the glass grid. The leaves of each plant were weighed and spread in several layers in trays. Discs of the laminae were cut out from random positions in the trays using a circular punch with a cross section of 2·65 cm^2.

Complete discs were selected and weighed in 5g and 10g samples. The number of discs in each sample was counted. The total leaf area was calculated by dividing the total weight of the leaves by the weight of the sample and multiplying the quotient by the total area of the discs. Measurements obtained by these two methods are given in *Table 1*.

In no case did the punch estimation differ from the grid values by more than two per cent of the measured area and it is concluded that the punch method using 10g samples per plant was sufficiently accurate for the determination of leaf areas.

Table 1. A comparison of the leaf areas of six cassava plants obtained by two methods of measurement, areas expressed as cm²

Plant No.	1	2	3	4	5	6
No. of leaves	60	102	54	72	59	128
Leaf area by grid method in cm²	4569·48	7989·50	3882·67	7624·19	4538·61	9100·11
Leaf area by punch method in cm²	4546·59	8042·22	3947·49	7693·06	4473·89	9187·13
Percentage error punch method (%)	−0·5	+0·6	+1·7	+0·9	−1·4	+1·0

Measurement of respiration rate of leaves

The measurements of the respiration rate of infected and healthy leaves were based on a method described by DUNLAP (1930). A detached leaf was suspended by its petiole in a sealed litre flask containing a dilute solution of barium hydroxide of known normality. The flasks were kept in the dark for five hours at 29°C. The carbon dioxide evolved by the leaf was estimated by titration of the residual barium hydroxide with standardized hydrochloric acid. Blank flasks, without leaves, were used to estimate the amount of atmospheric carbon dioxide contained in the flasks. The area of each leaf was measured by the glass grid method and the results expressed as the amount of carbon dioxide evolved in mg per hour per sq. cm of leaf. Although this method did not give very accurate values of the amount of carbon dioxide evolved, it was sufficiently precise, and the differences between infected and healthy leaves large enough, to make more refined methods unnecessary.

Estimation of nitrogen and carbohydrate content of leaves

Samples of leaves at similar stages of development were collected from infected and healthy plants at the three harvest dates. Samples of 100g were dried at 100°C and the total nitrogen determined by the micro-Kjeldahl method. Estimations of the percentages of moisture, ash, ether extract and crude fibre were made. The percentage of the total carbohydrate was obtained by subtracting the total of these percentages and that of protein nitrogen from one hundred.

Estimation of hydrogen cyanide content of tubers

The hydrogen cyanide content of peeled tubers, i.e. tubers from which the skin and rind had been removed, was measured for both healthy and infected plants. The method is described in the *Methods of Analysis of the Association of Official Agricultural Chemists* (ANON, 1945) and involves the hydrolysis of a grated sample of the tuber. The liberated hydrogen cyanide is steam-distilled off, trapped in sodium hydroxide solution, and titrated against standardized silver nitrate.

RESULTS

Field experiments

Results of the field experiments are summarized in *Table 2.*

Table 2. A comparison between leaf areas, tuber, stem and petiole weights of infected and healthy cassava plants harvested 4, 6 and 8 months from the time of planting

		4 month harvest		6 month harvest		8 month harvest	
		Mean	*S.E. of mean*	*Mean*	*S.E. of mean*	*Mean*	*S.E. of mean*
Tuber wt per plant	*Healthy*	360·0g	40·3	520·4g^{xxx}	71·3	766·9g^{xxx}	31·3
	Infected	296·5g		345·7g		549·5g	
Stem wt per plant	*Healthy*	294·0g	31·42	416·2g	54·09	519·4g	61·31
	Infected	350·6g		380·5g		472·3g	
Petiole wt per plant	*Healthy*	102·55g	9·30	145·1g	11·79	90·9g	10·70
	Infected	107·9g		125·9g		72·6g	
Leaf area per plant	*Healthy*	1·055m^3	0·94	1·95m^{2x}	0·17	1·12m^2	0·12
	Infected	1·325m^3		1·49m^2		0·95m^3	

It will be noted from *Table 2* that, for the duration of these observations, although there was a significant difference in yield between healthy and infected plants there was no significant difference between stem weights. The height and number of leaves of infected plants did not differ significantly from those of healthy ones at any of the harvests, i.e. although storage ability was apparently affected by the virus the growth of the stem was not.

Four months after planting the yield obtained from healthy plants was 17 per cent greater than that from infected ones, but this difference was not significant. Similarly at this stage there was no significant difference between the leaf areas, stem and petiole weights of infected and healthy plants. At six months the yield of healthy plants was 34 per cent greater than that of infected ones, the difference being significant. There was no significant effect of infection on stem and petiole weight but the leaf area was 24 per cent greater in healthy plants than in infected, the difference again being significant. In the harvest of the eight month old plants there was a significant difference of 29 per cent between the yield of infected and healthy plants although no significant differences were recorded for leaf area and stem and petiole weights.

Correlations between leaf area and yield were examined (*Table 3*). At the six month harvest there was a highly significant positive correlation between leaf area and root weight, but no such correlation was observed in infected plants. This harvest took place near the end of the rains when growing conditions were good; at this time symptom expression in the leaves reached maximum severity. During the dry season when the eight month harvest took place symptom expression was less marked and there was a highly significant positive correlation between leaf area and root weight in both infected and healthy plants.

Table 3. Correlation coefficients between yield and leaf area in infected and healthy plants 4, 6 and 8 months after planting

	4 month harvest	*6 month harvest*	*8 month harvest*
Healthy	0·582^{xxx}	0·97^{xxx}	0·619^{xx}
Infected	0·810^{xxx}	0·131	0·699^{xxx}

Carbohydrate/nitrogen determinations

The data obtained for the analysis of the percentage of protein nitrogen and total carbohydrate in the leaves sampled at noon are given in *Table 4.*

Table 4. Carbohydrate/nitrogen levels and ratios expressed as percentage of fresh weight, in comparable leaves of healthy and infected plants 4, 6 and 8 months after planting

		Carbohydrate	*Protein nitrogen*	C/N *ratio*
4 month	*healthy*	8·81	8·75	1·01
	infected	8·01	7·94	1·01
6 month	*healthy*	8·06	6·88	1·17
	infected	7·48	5·81	1·29
8 month	*healthy*	9·45	7·88	1·20
	infected	9·75	6·56	1·49

The lower level of carbohydrate in infected leaves implies that there may be a more rapid breakdown of carbohydrates, while the higher carbohydrate/nitrogen ratio in the infected leaves also indicates a similar rapid breakdown of organic nitrogen compounds. However, further investigations will be necessary to determine the photosynthetic ability of infected leaves.

Hydrogen cyanide analyses

No significant difference was found in the hydrogen cyanide content of peeled tubers from healthy and infected plants at any of the three harvests.

Respiration studies

Studies on respiration rates showed that infected leaves evolved carbon dioxide at an average rate of 0·0022 mg per hour per sq. cm of leaf when maintained for a period of five hours in the dark at a temperature of 29°C. Under similar conditions healthy leaves evolved carbon dioxide at the rate of 0·0018 mg per hour per sq. cm of leaf. The differences between the values from infected and healthy leaves were highly significant and the results indicate that there is a more rapid breakdown of carbohydrates in infected leaves. These are supported by the chemical analyses of infected and healthy leaves shown in *Table 4.*

SUMMARY

Observations over an eight month period on a selected cassava variety have shown that primary infection with cassava mosaic virus significantly reduces the yield, but no significant differences between stem and petiole

weights or hydrogen cyanide content of peeled tupers were recorded. There was a highly significant positive correlation between leaf area and yield in healthy plants but no such correlation was found in infected plants when symptom expression was at its maximum. At this time there is also a significant difference between the leaf areas.

The carbohydrate/nitrogen ratio of leaves taken from infected plants was greater than in comparable leaves taken from healthy plants although the actual percentages of carbohydrate and nitrogen were less. This may be an indication of a greater rate of breakdown of carbohydrate and nitrogen compounds in the leaves of infected plants. This may be supported by the fact that the respiration rate of leaves from infected plants kept in the dark was found to be significantly greater than that of comparable leaves from healthy plants.

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Recent Work on the Propagation of Coffee from Cuttings in Kenya

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By 1949 the propagation of *Coffea arabica* by cuttings had reached the stage when a standard technique had been evolved. Cuttings* composed of suckers of from 8 to 9 in. in length were prepared by making a wedge-shaped cut through a node. The cuttings were then dipped into Seradix B No. 1 and inserted in a glass-covered propagating frame. The rooting medium consisted of a one to one mixture of decomposed coffee hullings and clean river sand.

As a result of this technique a small percentage of cuttings produced roots at 3 months, the percentage increasing with each successive month until the sixth month, when something in the region of 50 per cent rooting was often obtained. From the sixth month onwards rooting deteriorated, but if the cuttings were permitted to remain in the frame for 12 months 100 per cent rooting was frequently achieved.

Though great progress had been made, it was considered that the propagation of coffee by cuttings was far from satisfactory if mass production of clonal material ever became necessary in Kenya. Since 1949 investigations have therefore been directed towards the establishment of a more uniform rooting period. As hormone treatment was likely to induce uniform rooting and consequently shorten the overall time which coffee cuttings normally take to root, it was decided to try out various root-promoting substances to study their influence on rooting.

As limited work appeared to have been carried out in Kenya on cutting types, this aspect was also investigated. Other investigations were concerned with the best time of day to remove cuttings from the parent tree and with rooting media and the hardening-off of the cuttings after removal from the propagators.

The various experiments to be described in this paper were carried out between the years 1950 and 1955 and represent the results of 37 trials involving 5100 cuttings.

Propagators

The propagators used in the trials were of the familiar standard nursery type constructed of stone with steel-framed, glass-covered lights. The bottoms of the propagators were covered with a layer of broken stones to a depth of 1 ft. On the top of this was placed a 6 in. layer of the rooting medium, or enough to bring the level to within 3 in. of the glass light at the lower side of the propagator.

Temperatures

Temperatures within the propagating frame were controlled by prevailing climatic conditions and by the amount of shade. Mean inside temperatures during the dry, hot season ranged from 77°F to 54°F.

*Cottington, E. (1949). 'Propagation of coffee from cuttings.' *Mon. Bull. Coffee Bd Kenya*, April

Figure 1. The propagating block

Figure 2. Interior of propagating block

Figure 3. When cuttings are removed from the hardening-off frame they are transferred to nursery beds which form an extension to the propagating block

Figure 4. Above left: an ideal shoot before the cutting is made, right: a prepared cutting of the nodal wedge type; below: rooted cuttings at the stage when they are ready for removal from the propagator

Shade

The propagators, which were laid out in an east–west direction, were covered with overhead shade material suspended on 6 ft high cedar posts. The west side was also shaded and a nearby banana plantation provided shade on the north side, while the south side was unshaded. During the period of the experiments, various materials were used to provide overhead shade. The materials consisted of hessian, papyrus mats and light leafage such as grass, banana fronds and papyrus. The two former materials, though providing excellent shade during the brighter and hotter seasons, proved to be too heavy for the colder, duller seasons. Moreover both materials lacked durability and consequently had to be replaced at quite frequent intervals. The latter materials consisting of leafage were a more recent development which provided for a measure of control over the amount of shade.

To enable leafage material to be supported successfully, the propagating block was roofed with 2 in. mesh wire netting. The leafage was then placed on the netting and by increasing or decreasing the amount, shade density over the propagators was quickly and easily controlled.

Treatment of cuttings after insertion

On insertion, the cuttings were lightly watered in and thereafter humidity was maintained by a single, or twice-daily foliar mist spray. Spraying was carried out twice daily during the hotter and brighter periods and was just sufficient to wet the foliage of the cuttings and the walls of the propagators. When drying out of the soil was observed watering by can was carried out.

3 months after insertion the cuttings were lifted. Those which had produced roots were transferred to the hardening-off frames, and the unrooted cuttings were returned to the propagators. Thereafter the cuttings were lifted at monthly intervals until the sixth month when unrooted cuttings were discarded.

Root-promoting substances

The influence of various root-promoting substances on the rooting of coffee cuttings is shown in *Table 1.*

The type of cuttings used consisted of uniform, green, semi-ripe terminal growths from sucker shoots which, when trimmed ready for insertion, were of 2 or 3 nodes and between 4 and 5 in. in length. All axillary growths were removed and the larger leaves were reduced in size by cutting away a half. Cuttings were made by making a wedge-shaped cut through the node. The prepared cutting was then dipped into the root-promoting substance in the manner shown in the table and then inserted in the propagator.

As the object of the treatment was to study the influence of root-promoting substances on the acceleration of rooting and the promoting of a more uniform rooting period, the treatments considered to be the most useful were those which accelerated rooting during the third and fourth months and those which increased the total percentage of cuttings rooted at 6 months.

Hortomone A in powdered form at 5 per cent concentration had the greatest influence on accelerating rooting at 3 months after insertion of the cuttings though there was no marked influence on the total percentage rooting at 6 months. The range of concentrations of Hortomone A in

Table 1. The quantities shown in Nos. 1, 4, 5, 6, 7 and 8 were placed in 100 c.c. consisting of half tap water and half ethyl alcohol

Growth-promoting substances	*Concentrations*	*Percentage cuttings rooted at months after insertion (cumulative)*			
		3	4	5	6
1. *Hortomone 'A' 2 sec dip*	0·125 c.c.	15·0	48·0	61·0	68·0
	0·25 c.c.	3·0	14·0	27·0	32·0
	0·5 c.c.	5·0	14·0	34·0	44·0
	0·75 c.c.	9·0	20·0	35·0	42·0
	1·00 c.c.	15·0	40·0	53·0	56·0
2. *Hortomone 'A' 22 h dip*	12 *drops in* 1 *pint water*	5·0	5·0	24·0	24·0
3. *Hortomone 'A' in powder; basal covering*	0·25%	*Nil*	16·0	33·0	44·0
	0·5%	45·0	53·0	66·0	69·0
	0·75%	33·0	33·0	33·0	44·0
	1·0%	39·0	46·0	56·0	80·0
	1·25%	11·0	15·0	17·0	21·0
	1·5%	15·0	16·0	16·0	37·0
	1·75%	*Nil*	*Nil*	*Nil*	22·0
	2·0%	16·0	30·0	34·0	41·0
	5·0%	60·0	67·0	77·0	77·0
4. *β-Indolyl-butyric acid 2 sec dip*	0·125g	31·0	58·0	71·0	75·0
	0·25g	34·0	50·0	72·0	72·0
	0·375g	4·0	14·0	32·0	43·0
	0·5g	13·0	43·0	48·0	48·0
	0·625g	4·0	4·0	33·0	38·0
	0·75g	8·0	8·0	8·0	8·0
5. *α-Naphthalene-acetic acid 2 sec dip*	0·125g	33·0	50·0	83·0	83·0
	0·25g	41·0	75·0	75·0	91·0
	0·5g	16·0	66·0	75·0	75·0
	0·75g	8·0	58·0	91·0	91·0
	1·0g	27·0	32·0	46·0	50·0
	1·25g	*Nil*	5·0	10·0	20·0
	1·5g	*Nil*	5·0	10·0	25·0
	1·75g	5·0	10·0	30·0	40·0
	2·0g	5·0	5·0	5·0	5·0
6. *β-Indolyl-acetic acid 2 sec dip*	0·125g	33·0	50·0	83·0	83·0
	0·25g	41·0	75·0	75·0	91·0
	0·5g	16·0	66·0	75·0	75·0
	0·75g	8·0	58·0	91·0	91·0
	1·0g	28·0	57·0	64·0	65·0
7. *Dichlorophenoxy-acetic acid 2 sec dip*	0·125 c.c.	8·0	30·0	45·0	53·0
	0·25 c.c.	14·0	21·0	42·0	42·0
	0·5 c.c.	21·0	42·0	71·0	71·0
	0·75 c.c.	8·0	43·0	52·0	52·0
	1·0 c.c.	*Nil*	28·0	50·0	50·0
8. *Seradix 'A' 2 sec dip*	0·25 c.c.	31·0	45·0	53·0	55·0
	0·5 c.c.	23·0	38·0	54·0	59·0
	0·75 c.c.	29·0	55·0	60·0	60·0
	1·0 c.c.	36·0	50·0	60·0	60·0
9. *Seradix 'B' No. 1; basal coating*	*Nil*	23·0	39·0	54·0	69·0
10. *Cows' urine 2 sec dip*	1:100 *parts water*	32·0	61·0	61·0	61·0
	1:3 ,, ,,	13·0	13·0	13·0	57·0
	1:1 ,, ,,	26·0	39·0	42·0	42·0
	3:1 ,, ,,	*Nil*	26·0	26·0	42·0
	Full strength	*Nil*	*Nil*	*Nil*	71·0
11. *Boiling water*	1 *sec dip*	*Nil*	*Nil*	20·0	40·0
	2 ,, ,,	*Nil*	*Nil*	30·0	50·0
	3 ,, ,,	*Nil*	*Nil*	10·0	20·0
12. *Control—tap water dip*	*Nil*	21·0	48·0	62·0	73·0

powder showed conflicting results. In the lower range of 0·25 to 1·0 per cent the 0·5 per cent concentration appeared to be the optimum for accelerating rooting at 6 months. With an increase in concentration up to 2·0 per cent considerable suppression resulted but when the 2·0 per cent concentration was more than doubled, unexpected acceleration of rooting resulted.

β-Indolyl-butyric acid at 0·125 g and 0·25 g both accelerated rooting during the third and fourth months but did not have any significant influence on the total percentage rooting at 6 months.

α-Naphthalene-acetic acid in the 0·25 g concentration not only accelerated rooting during the third and fourth months but also greatly increased the overall percentage of cuttings rooting at 6 months. β-Indolyl-acetic acid at 0·25 g accelerated rooting during the third and fourth months and also increased the total percentage of cuttings rooting at 6 months.

Cow's urine at 1·0 c.c. in 100 c.c. of water accelerated rooting at the third and fourth months but did not increase the total percentage rooting at 6 months.

Table 2. Hormone treatment before and after insertion

Percentage rooted at months (cumulative)	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)
3	10·0	3·34	3·34	*Nil*	*Nil*
4	16·67	3·34	6·68	*Nil*	5·12
5	50·0	6·68	10·0	*Nil*	15·0
6	53·4	6·68	10·0	*Nil*	38·34

(*a*) Treatment applied at the time of insertion.
(*b*) Treated at time of insertion and again at 2 months.
(*c*) Treated at 2 months after insertion.
(*d*) Treated before insertion and the callus lightly pared at 2 months.
(*e*) Treated before insertion and again at 2 months after paring of the callus.

Though many of the treatments failed to accelerate or increase the overall percentage of cuttings rooted, there was a very marked improvement in root development as a result of all the treatments except the boiling water treatment.

Following this experiment, a further trial was put down to study the influence of a root-promoting substance, Seradix B No. 1, when applied to cuttings before and after insertion. The cuttings were of the nodal wedge type. *Table 2* shows the results and the indications were that root-promoting substances were likely to exert the greatest influence when applied to cuttings at the time of insertion.

Cutting types

Though the nodal wedge type cutting had produced good results, very little information was available concerning the rooting performance of other cutting types and consequently it was decided to try several types of cuttings to find out what type would produce the best results. *Tables 3*, *4*, *5* and *6* show the types of cuttings used and the rooting results achieved.

The nodal and internodal type cuttings as shown in *Table 3* consisted of uniform, green semi-ripe, firm sucker shoots which, when trimmed ready for insertion, were of two or three nodes and about 5 in. in length. Comparison

Table 3. Nodal and internodal type cuttings

Percentage rooted at months (cumulative)	*Nodal cuts*				*Internodal cuts*			
	Control (wedge)	*Horizontal*	*Oblique*	*Split*	*Wedge*	*Horizontal*	*Oblique*	*Split*
3	41·0	14·0	14·0	14·0	23·0	14·0	17·0	14·0
4	62·0	35·0	38·0	35·0	54·0	51·0	44·0	28·0
5	62·0	42·0	38·0	42·0	68·0	51·0	49·0	46·0
6	64·0	45·0	58·0	46·0	68·0	64·0	68·0	64·0

of the nodal and internodal type cuttings shows that the nodal wedge-shaped cutting gave the best results during the third and fourth months. The rooting percentage at the fifth and sixth months after insertion, however, indicates that all the internodal type cuttings were superior.

Table 4 shows the rooting performance of 1, 2 and 3 noded, semi-ripe cuttings and also 3 noded cuttings which had all the leaves removed except the first set. The table also shows the rooting results of cuttings with the apical growth removed to the first set of leaves. The rooting results with hardwood cuttings are also shown.

Table 4. Nodal wedge type cuttings

Percentage rooted at months (cumulative)	*1 node*	*2 nodes*	*3 nodes*	*3* nodes*	*3 nodes: apical growth removed*	*3 nodes: hard-wood*
3	12·0	9·0	18·0	20·0	32·0	*Nil*
4	12·0	16·0	36·0	25·0	36·0	10·0
5	16·0	38·0	54·0	45·0	46·0	15·0
6	28·0	45·0	63·0	55·0	56·0	20·0

* All leaves except the first set removed.

The results show that the 3-noded, semi-ripe cuttings were superior to the 1 and 2 noded types and to the 3 noded type which had the leaves removed. Though removal of the apical growth did not increase the total percentage of cuttings rooting there was a favourable influence on rooting during the third and fourth months which compared with the performance of the 3 noded cuttings with the apical growth intact.

To extend the work on cutting types, a trial was put down to compare the rooting performance of mallet and heeled type cuttings with semi-ripe, nodal wedge type cuttings which had so far given the best rooting results. *Table 5* shows the results of the types of cuttings used in the trial.

Table 5. Mallet and heeled type cuttings

Percentage rooted at months (cumulative)	*Control*	*(a)*		*(b)*		*Heeled types*		
	Nodal wedge	*Mallet*	*Split mallet*	*Mallet*	*Split mallet*	*6 in.*	*2 in.*	*1 in.*
3	28·0	*Nil*	*Nil*	*Nil*	*Nil*	18·0	*Nil*	*Nil*
4	56·0	*Nil*	12·0	*Nil*	*Nil*	10·0	6·0	*Nil*
5	72·0	*Nil*	16·0	16·0	50·0	18·0	12·0	*Nil*
6	80·0	4·0	28·0	33 0	50·0	37·0	12·0	*Nil*

(*a*) The diameter of the mallets was five-eighths of an inch and the attached shoots were about 8 in. in length.
(*b*) The diameter of the mallets was three-eighths of an inch and the attached shoots were about 4 in. in length.

The nodal wedge type cutting again showed superiority. Though the heeled type cuttings of 6 in. in length were superior to the mallet types, there appeared to be little promise in these two types of cuttings. The mallet type cuttings were made by cutting out 1 in. sections from the bent-over young stems of the parent plants to which suitable suckers were attached. Callusing of the split mallets was quick but very heavy, which may have accounted for the nil or poor rooting during the third and fourth months.

The heeled cuttings also originated from bent-over stems of the parent plant and were made by removing the suckers from the parent stem by means of a quick sharp pull. A very light trimming of the heeled surface followed and the cutting was ready for planting.

Table 6. Single leaf and wedge cuttings

Percentage rooted at months (cumulative)	*Single leaf (nodal)*	*Single leaf (internodal)*	*Scraped wedge (nodal)*	*Control: nodal wedge*
3	*Nil*	10·0	*Nil*	15·0
4	10·0	25·0	*Nil*	25·0
5	45·0	25·0	10·0	40·0
6	55·0	35·0	25·0	57·0

The rooting of semi-ripe, single leaf cuttings of the nodal and internodal types was also compared with scraped and unscraped semi-ripe, nodal wedge type cuttings. Single leaf nodal cuttings were made by making a wedge-shaped cut through the basal node of the shoot. The other cut was a horizontal one made about half an inch above the first set of leaves. One of the leaves was removed and the cutting was then ready for insertion, being planted so that the axil of the leaf was at soil level. Preparation of the internodal cuttings was identical except that the basal cut was through the internode at about half way between the two nodes. The scraped and unscraped wedge, nodal type cuttings were of 3 nodes with the scraped cuttings having the bark lightly scraped away almost down to the cambium for about 1 in. in the basal region of the cuttings.

Table 7. Times at which cuttings were removed from parent trees and rooting results

Percentage rooted at months (cumulative)	8 *a.m.*	9 *a.m.*	10 *a.m.*	11 *a.m.*	12 *noon*	1 *p.m.*	2 *p.m.*	3 *p.m.*	4 *p.m.*	5 *p.m.*
3	28·0	35·0	21·0	24·0	24·0	17·0	17·0	*Nil*	7·0	7·0
4	71·0	56·0	42·0	49·0	53·0	57·0	35·0	21·0	46·0	35·0
5	74·0	67·0	74·0	67·0	71·0	71·0	53·0	42·0	64·0	46·0
6	78·0	78·0	76·0	74·0	73·0	74·0	57·0	53·0	74·0	53·0

Table 6 shows the result of this trial and once again it was the semi-ripe, 3 noded, nodal wedge cutting which gave the best results. Scraping of the basal end of the cutting, which it was hoped would result in speedy callusing with quicker root production, not only suppressed rooting during the third and fourth months but also reduced the total percentage of rooting over the whole 6 months period.

Time of removal of cuttings from parent tree

Since the time of the day at which the cuttings were removed from the parent tree was likely to influence rooting, trials were instituted so that cuttings could be taken at hourly intervals between 8 a.m. and 5 p.m. The results are shown in *Table 7.*

The results show that semi-ripe, 3 noded, nodal wedge type cuttings removed from the parent tree at 8 a.m. and planted immediately produce the best rooting and that the morning period 8 a.m. to 1 p.m. is likely to be the best period of the day to take cuttings.

Rooting media

Although a one to one mixture of decomposed coffee hullings and river sand had proved to be a good rooting medium for coffee cuttings it was decided to investigate other media to find out if any other mixtures or substances would prove more suitable.

Table 8. Rooting results from various media

Percentage cuttings rooted at months (cumulative)	Vermiculite							
		In river sand				In red soil	In river silt	
	100%	1:1	1:2	1:3	1:4	1:1	1:1	1:2
3	1·0	8·0	13·0	*Nil*	*Nil*	8·0	44·0	*Nil*
4	1·0	8·0	33·0	*Nil*	*Nil*	22·0	64·0	6·0
5	3·0	19·0	46·0	*Nil*	6·0	42·0	81·0	20·0
6	16·0	27·0	60·0	3·0	16·0	62·0	88·0	34·0

Percentage cuttings rooted at months (cumulative)	River sand				River silt	Coffee hullings	
		In red soil				In river sand	
	100%	1:1	1:2	1:3		1:1	1:6
3	2·0	46·0	26·0	21·0	37·0	2·0	*Nil*
4	7·0	57·0	45·0	38·0	66·0	13·0	5·0
5	9·0	82·0	55·0	68·0	78·0	30·0	9·0
6	25·0	82·0	80·0	72·0	85·0	52·0	23·0

Several media were tested and the results are shown in *Table 8.* Vermiculite in river silt at a one to one mixture and river silt by itself gave the best results in this trial. Both had a marked influence on increased rooting during the third and fourth months and also increased the overall percentage of cuttings rooted. River sand and red soil in a one to one mixture also increased rooting and is considered as good as vermiculite in river silt at the one to one mixture or river silt by itself. Vermiculite or sand used by themselves proved to be worthless, but of the 15 media tested 8 proved to be superior to the one to one mixture of coffee hullings and river sand.

Influence of climatic conditions on rooting

As climatic conditions were expected to exert considerable influence on rooting, an analysis of the rooting results of semi-ripe, nodal wedge cuttings over a one-year period was made. The result of the analysis on a month by month basis, together with rainfall and temperatures, is shown in *Table 9.*

The results show that cuttings root best between March and June which

coincides with the long rainy season. October and November also proved favourable for rooting. Both months show increases in rainfall which coincided with the short rainy season. Rooting therefore appears to be influenced by rainfall rather than by temperature.

Table 9. Rooting results on a month to month basis

Percentage rooted at months (cumulative)	*Jan*	*Feb*	*March*	*April*	*May*	*June*
3	*Nil*	2·0	20·0	57·0	70·0	*Nil*
4	5·0	12·0	50·0	61·0	81·0	85·0
5	18·0	17·0	76·0	83·0	90·0	92·0
6	20·0	22·0	80·0	92·0	94·0	100·0
Rainfall in.	0·02	0·51	4·61	16·32	4·73	5·63
Temp.: max. °F	87·6	88·4	85·0	79·5	75·9	76·4
min. °F	48·8	49·0	51·4	55·9	53·8	48·5

Percentage rooted at months (cumulative)	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*
3	28·0	*Nil*	30·0	10·0	42·0	35·0
4	39·0	20·0	36·0	22·0	53·0	42·0
5	41·0	46·0	55·0	59·0	64·0	42·0
6	57·0	60·0	60·0	67·0	68·0	50·0
Rainfall in.	1·11	1·71	0·65	3·86	6·36	0·45
Temp.: max. °F	76·0	76·0	82·3	82·6	79·2	85·3
min. °F	47·2	48·3	44·8	54·3	55·1	48·5

Hardening-off of rooted cuttings

Though great progress in the rooting of cuttings had been achieved by 1949, no satisfactory technique had been evolved whereby rooted cuttings could be hardened off successfully.

The hardening technique which was followed necessitated the potting of rooted cuttings into banana pots. The potted cuttings were then placed into glass-covered frames which were situated within the propagating block. When the plants had established themselves, which took from 7 to 10 days, the lights were gradually raised to admit air. By the tenth day the frames were fully opened and the cuttings were allowed to remain in the shelter of the hardening-off frame for a further 14 days. They were then removed from the frame and placed under the overhead shade of the propagating block. From then on losses resulted due to various causes, the main causes being the decay and collapse of the banana pots during the rainy season and failure to keep the potted cuttings moist enough during the dry season. Growth rate under these conditions was also very slow, especially during the hot dry season. Losses by the potting technique frequently reached 50 per cent.

By 1952 a new technique was evolved which eliminated the need to pot the cuttings on removal from the propagators. With the new technique cuttings were removed from the propagating frame and planted in glass-covered hardening-off frames containing a mixture of 3 parts red soil and 1 part manure. From then on, until removal from the hardening-off frame, the hardening-off process remained the same as before. On removal from the hardening-off frame, the bare root cuttings were planted in well composted shaded beds which formed an extension to the propagating block. The cuttings remained in the beds until ready for planting in the field.

DISCUSSION

The results show that certain growth-promoting substances accelerated rooting during the third and fourth months after insertion and increased the overall percentage of rootings at 6 months. The treatments which exerted the greatest influence (*Table 1*) were the Hortomone A 5 per cent concentration in powder form, α-naphthalene-acetic acid at 0·75 g as a 2-second dip and β-indolyl-acetic acid at 0·25 g also as a 2 second dip. These 3 substances in the concentrations given above all accelerated rooting during the third and fourth months and also increased the total percentage of cuttings rooted at 6 months. Though the Hortomone A treatment did not greatly increase rooting at 6 months the increases resulting from β-indolyl-acetic acid and α-naphthalene-acetic acid were very marked.

For the purpose of increasing the output of cuttings it may be better to discard any unrooted cuttings after the fourth month rather than retain them for 6 months. Taking the α-naphthalene-acetic acid treatment as an example, the annual output could be increased from 192 cuttings to 225 cuttings. The first value represents the 91·0 per cent rooting which was obtained as a result of the treatment at 6 months. The second value represents the 75·0 per cent rooting obtained at 4 months. By converting these percentages to represent the numbers of cuttings rooted at 6 months and then doubling and trebling them respectively to represent the output over a 1 year period the value of the shorter rooting period can be seen.

There is little doubt that the time to apply root-promoting substances is at the time of insertion. There was some indication that re-application of the hormone, after paring the callus at 2 months after insertion, may stimulate rooting. It is possible that if paring of the callus had taken place at 1 month after insertion better rooting might have resulted. But unless rooting could be considerably increased by such treatment, the lifting of cuttings for paring of the callus and re-application of a hormone would not be practicable.

Of the different types of cuttings investigated, the green, semi-ripe, nodal wedge type made from terminal growths taken from suckers proved to be superior to any other type (see *Table 3*), especially during the third and fourth months. The internodal type cuttings did, however, produce a higher percentage of rooting at the fourth, fifth and sixth months than the nodal types. It may well be that further work on the internodal type cuttings may result in increased rooting. The internodal cuttings used in the trial were prepared by making the cut half way between the nodes. Further investigations should therefore be concerned with the point between the nodes

at which the cut should be made. It is possible that the position of the cut may have considerable influence on rooting.

The time of day at which the cuttings were removed from the parent tree had a considerable influence on rooting. Though the cuttings taken at 8 a.m. produced the best results up to the fourth month there was no great difference between the 8 a.m. and the 1 p.m. rooting at 6 months. However, since the object of the trials was to find ways of reducing the rooting period, 8 a.m. is considered to be the best time of the day to take cuttings. If cuttings taken at 8 a.m. are allowed to stay in the propagators for 4 months instead of 6 months then the annual output might be increased, as was also demonstrated as a result of the more favourable growth-promoting treatments.

Of the rooting media used in the trials, vermiculite in river silt in a one to one mixture and river silt by itself produced the best results at both the fourth and sixth months. The river silt used in the trials was collected after river floods had subsided and on mechanical analysis the main constituents were, clay 44·3, sand 31·0 and silt 9·2 per cent, i.e. not unlike a light loam soil. Since it has never been possible to secure identical supplies of the silt it is considered that river sand and red soil in a one to one mixture is the most suitable rooting medium. The red soil is the familiar Kenya red coffee soil which is easily obtained, as is also the river sand, thus making this particular rooting medium a practical proposition. Coffee hullings and sand in a one to one mixture tend to produce fluctuating results on account of the differences in the state of decomposition at the time of use.

Table 9 shows that coffee cuttings root best during the rainy seasons. In view of this, it may be possible that the mist spray method which has given such good results on the rooting of cacao may prove of value in rooting coffee. This is a feature which has not been investigated in Kenya but which may well be worth trying both in closed propagating frames and in open beds.

SUMMARY

Growth-promoting substances are capable of accelerating the rooting of *Coffea arabica* cuttings by increasing the percentage of cuttings rooting during the third and fourth months following insertion.

Of the substances used, Hortomone A at a 5 per cent concentration as a powder treatment, α-naphthalene-acetic acid at 0·75 g and β-indolyl-acetic acid at 0·25 g in 100 c.c. of liquid made up as half and half tap water and ethyl alcohol, and used as 2-second dips were the most promising treatments.

The best type of cutting was the green, semi-ripe, 2 or 3 noded, nodal type taken from terminal sucker growths and prepared by making a wedge-shaped cut through the node.

Though the most favourable rootings resulted when cuttings were taken at 8 a.m., good results were also achieved from cuttings taken between 8 a.m. and 1 p.m.

Vermiculite and river silt at a one to one mixture, and river silt by itself, proved to be the best rooting media. For practical purposes a one to one mixture of red soil and river sand can be expected to produce almost as good rooting results.

Cuttings rooted best during the rainy seasons. (*Received July 1957*)

Book Reviews

MECHANIZATION OF TROPICAL CROPS

W. N. Bates. Temple Press: London, 1957. xiii + 410 *pp.* (illus.) 45*s*

This is a useful book which makes a valuable contribution to the information available about the application of machinery to tropical agriculture.

In the introduction it is stated that the scale of the subject is large and that the planning of the text proved difficult. In presenting the general problems of tropical mechanization in Part II of the book, and then dealing with the mechanization of specific crops in Part III, the author has more than adequately overcome the planning difficulties to which he refers and is to be complimented on the result achieved. The majority of Part I, however, would probably have been better omitted. A full discussion of subjects like 'Tropical soils in relation to climate', 'Soil erosion and conservation' and 'Drainage and irrigation' would demand a complete book on each, and the accounts included in this text have been so limited in the interests of brevity that they serve little real value and may even be misleading through over-simplification.

Parts II and III of this book, on general mechanization and mechanization of specific crops respectively, contain a great deal of useful information, and the relative emphasis laid upon the different sections in Part II reflects the author's close and practical association with mechanization in the tropics. There has often been an unfortunate tendency for the mechanization of tropical agriculture to be considered as an end in itself. It is particularly fortunate, therefore, that the first text to be written about agricultural mechanization in the tropical areas of the British Commonwealth should be characterized by a balanced approach to the subject. The importance of mechanization is not over-emphasized in relation to other means of increasing agricultural production, machines are discussed in relation to the agricultural systems which they are to serve and due consideration is given to the very considerable problems which arise from the economic, cultural and social backgrounds of those who may operate the equipment.

This book fulfils a long-felt want in the range of texts available on agricultural machinery and will be of value to all concerned with crop mechanization in the tropics. It will also assist those concerned in the manufacture of machinery to understand better the operating conditions for which their equipment should be designed.—P.H.R.

THE STATE OF FOOD AND AGRICULTURE 1957

United Nations Food and Agriculture Organization, 1957. viii + 171 *pp.* (illus.) 10*s*

This volume adds another chapter to FAO's authoritative reviews of current conditions in world agriculture. It is not quite so impossibly up to date as the title implies, but nearly so: some of the analyses are carried

up as far as the first four months of 1957, and all of them go at least as far as 1956. This is no mean achievement in a report of such wide scope and greatly adds to its value. The report includes useful reviews presented product by product; concise, up to date reviews of markets, production and other conditions can be found for all the main products that are of interest to the tropical agriculturist.—A.L.J.

SUPPLEMENT TO A WORLD DICTIONARY OF BREEDS, TYPES AND VARIETIES OF LIVESTOCK

I. L. Mason. Commonwealth Bureau of Animal Breeding and Genetics: Commonwealth Agricultural Bureaux, Farnham Royal, Bucks. (Supplement to *Technical Communication No. 8.*) 1957. 52 *pp.* 7*s* 6*d*

This supplement contains numerous additions and corrections to the original dictionary published in 1951. It is an essential purchase for libraries which possess copies of the original work.

The author of a work of this kind is at the mercy of his overseas correspondents and of the technical references appearing in the literature. The aim must be to reduce as well as to standardize the plethora of breed and varietal names which at present confront the student of the world's livestock. The danger is that a book of this sort will goad workers into filling in what they consider to be important omissions, until eventually every district and county name is included. This is particularly prone to occur in the more undeveloped parts of Africa where each tribe and sometimes each clan consider their livestock to be of a type distinctive from any other. An objective appraisal of the situation soon reveals that many such local varietal names are merely synonyms.

A further danger is that new 'Breeds' will be recognized before they have been developed into what the author defines as 'True Breeding Populations'. A few readers may have doubted whether the 'Santa Gertrudis' cattle were sufficiently developed to be included as a 'True Breeding Population' in the 1951 dictionary, but many workers will query the recent new addition of such breeds as the Bonsmara, which have only been developed (so the *Supplement* informs us) since 1938, and have not yet (again according to the *Supplement*) been granted *Herd Book* or Breed Society status.

There is a tendency for 'improved' forms of livestock, bred on government stations, to be known by the name of the stations even though all that has been done is to practise high level selection in an originally heterogeneous population or possibly to follow a programme of top crossing. The author of the dictionary must be on his guard to prevent such local groups of improved livestock precociously acquiring breed status.

Part II of the *Supplement* presents further information about the breed distribution in major livestock countries, and is a considerable improvement on the similar section of the original work.

If further development of this *World Dictionary* can actively reflect the need for a more intensive culling of the livestock it lists, it will fulfil a most valuable role in the field of livestock improvement.—P.N.W.

PROGRESS IN THE PHYSIOLOGY OF FARM ANIMALS, Vol. III

Edited by J. HAMMOND. Butterworths Scientific Publications: London, 1957. v+741–1043; combined index 28 *pp.* (illus.) 50*s*

The publication of the third volume of *Progress in the Physiology of Farm Animals*, albeit minus the chapter on male fertility which is still in preparation, completes a most valuable contribution to the literature on this broad field of animal husbandry research. As in previous volumes the contributions of a chapter on each topic by a specialist worker plus the thorough provision of references make this book an authoritative source of information.

The two main themes in this third volume are a continued study of present knowledge of the physiology of reproduction and a section containing three chapters on milk production. The first chapter on reproduction deals with the important subject of reproductive hormones and covers rather briefly the range of substances and mechanisms involved. The influence of the pituitary, gonads and placenta are described individually and in conclusion the hormone regulation of the oestrus cycle is explained in the light of recent work. The greater part of the second chapter on female fertility is devoted to an account of normal fertility in female reproduction leading on to methods of augmenting fertility followed by a brief discourse on causes of depressed fertility. These two chapters are followed by a long and comprehensive account of all aspects of pregnancy. The aspects covered range from morphology of the developing foetus, nutritional aspects, pre-natal mortality and parturition to a consideration of the many causes of abnormality and breakdown of the normal processes during pregnancy.

The second major section (on milk production) contains chapters on mammary development and lactation, factors affecting the rate of secretion of milk and lactation yields, and factors affecting milk composition. Active research is yielding fresh discoveries in these three main fields of study at a considerable rate and these chapters represent a most valuable milestone at which a thorough survey of present knowledge has been made. This has been the chief purpose of the whole series of volumes and in doing so the result has been to provide the student and research worker with an unequalled source of up-to-date information. In these days of rapid advance in all fields of scientific research any successful attempt to accomplish the difficult task of surveying the present state of knowledge is of great value. These three volumes represent such an attempt and form a unique contribution to the available literature on animal physiology.—T.R.H.

CITRUS-GROWING IN AUSTRALIA

F. T. BOWMAN. Angus and Robertson: London and Sydney, 1956. 311 *pp.* (illus.) 63*s*

This book is a general treatise on the cultivation and history of citrus in Australia, and deals with problems associated with the growing of the crop from the selection of variety and rootstock right through to the final marketing of harvested fruit. It is primarily intended for the commercial grower. It is important, however, to note, as shown by the diagram on page 64, that the bulk of citrus grown in Australia is found in the subtropical regions and hence many of the aspects dealt with are not necessarily applicable to tropical areas.

The book is well written and excellently produced, with good illustrations and adequate bibliography and index, but seemingly rather expensive for the average reader. It must be remembered though, that whilst it is a most useful addition to the world bibliography on citrus, its value outside Australia would appear to be limited to teachers and students interested in comparing the methods of production of one place with another.—J.S.C.

PRACTICAL ANIMAL BIOLOGY FOR THE TROPICS

R. D. PURCHON. University Tutorial Press: London, 1957. xii+148 *pp.* (illus.) 7*s*

The author points out in his preface that this book is based on the first year course in zoology for science, medicine, dentistry and pharmacy students in the University of Malaya; it is also for use in schools. But this does not detract from its utility elsewhere.

The emphasis throughout the book is not so much on facts as on training the students in perception, accuracy and drawing, and on making them think for themselves. The author points out (page x) that specific drawings are not asked for, the student is expected to judge for himself what should or should not be drawn. Commendable though this attitude is, it is doubtful if the first year student possesses the critical faculties to profit fully from this method of training.

As a result of this the book would be improved by the addition of more drawings of dissections of the general body cavities, showing the relative positions of the main organs, but if, as recommended, it is used in conjunction with *Animal Biology* (GROVE, A. J. and NEWELL, G. E., 1957), then the text figures will suffice.

The scope of the book is wider than that of some other authors in that it covers the Toad (in lieu of Frog), Dogfish, and Guinea-pig (in lieu of Rabbit) in full, and in less detail, Protozoa, Coelenterata, Platyhelminthes, Nematoda, Annelida, Crustacea, Insecta (Cockroach and some ectoparasites), other Arthropoda, some Mollusca and Echinodermata. The brain and skeleton of the Dog and the heart of the Sheep are described in detail. Some simple experiments on the physiology of digestion are included.

The descriptions would be of more use in other tropical countries if the genera used in the book were named; this particularly applies in the case of the vertebrate dissections. The chapters on comparative vertebrate embryology and histology and on cytology are of doubtful value in the absence of the slides referred to.

To have compressed this wide range of topics into a book of this size deserves great credit, for the detail and instructions are fully adequate for a first year course in which the demonstrator is in any case going to devote most of his time to teaching skills.

But perhaps the most important advantage this book has over its competitors is its price of 7*s*, which brings it well within the purse of overseas students who would be very reluctant to buy a more expensive volume.

Though some of the descriptions are based on the local fauna, the book should be in demand in many other tropical territories.—M.G.E.

THE STUDY OF THE SOIL IN THE FIELD

G. R. Clarke. 4th edn. Clarendon Press: Oxford, 1957. 204 *pp.* (6 plates) 35*s*

This book was first published in 1936, revised in 1938, and then produced in 1941 as a third edition by adding as an appendix the 27-page text of a field handbook for the official soil survey of England and Wales. It was an inexpensive $4\frac{1}{2} \times 7$ in. book (it is now $5\frac{1}{2} \times 8\frac{1}{2}$ in.) explaining admirably the work of characterizing soils in the field by the study of profiles together with that of the site features of topography, vegetation, etc. It provided a book of instruction for the inexperienced soil surveyor or for the forester, agronomist, or research worker in geography who needed to recognize and record the types of soil found in the course of his work; it was very valuable to any soil man for its many useful reminders and practical suggestions, and more so for its many interesting and thought-provoking comments upon features observed in soils of various lands.

The third edition originally cost 6*s* 6*d* in 1941, and a recent reprint cost 12*s* 6*d*. The great increase in price of the fourth edition is out of all proportion to the increase in length over that of the third. The increase in length is about 42 per cent, this being equally due to revision and expansion of the old subject matter, including that of the field handbook, and to the addition of a new section on air photographs and their use. The book should continue to be useful to many, especially Section II (of 68 pages) on soil-profile description. Nowadays most soil men would base their work largely on the comprehensive American *Soil Survey Manual* of 1951 (sold for only $3.00), which includes a very detailed scheme for the description of soil horizons, drainage, colour, organic matter, texture, structure, etc.; this contains much interesting explanatory material, but it may seem indigestible to non-specialists. Mr Clarke has included effective summaries of what the *Manual* says on several points.

Mr Clarke shows that the meaning of the ' soil series ' (the most important mapping unit) has been very similar in England and Wales and the U.S.A., and mentions that the soil surveys in Scotland have recently come into line. Genetic horizons, including organic layers, are almost identically labelled. *Munsell Charts* are the accepted standards for colour. The Scottish Memoir on *The Soils Round Jedburgh and Morebattle* (1956), summarizing the standard terms used, shows also a close conformity with the American *Manual* in regard to slope classes (' moderately steep ', ' steep ', etc.), texture, structure, and consistency. The Americans define soil texture strictly by mechanical composition, and base their field estimates on comparison with reference samples for particular kinds of soil. They have twelve texture classes defined on a triangular diagram by percentages of sand, silt and clay, but they have a silt fraction of 0·05 to 0·002 mm diameter instead of that of 0·02 to 0·002 mm as in the ' international ' scale which has been used elsewhere. There are advantages both in the wider limits of ' silt ' and in the texture classes as defined by the Americans, and their general adoption, as in Scotland, is desirable. It seems that England and Wales will follow suit, and on page 64 Mr Clarke gives descriptive notes for recognition of the same twelve classes by feel in normal soil samples.

The revised sections on soil structure and ' soil constitution ' (porosity, compactness, and consistency) are particularly useful. They indicate that there is still something lacking in the formal scheme of description of the Americans, and that this is largely a matter of soil porosity. The importance of recording as fully as possible the effects of fauna and roots is emphasized. Some mention might well have been made of the study of percolation rates and pore-size distribution, using core samples, which may be more satisfactory for assessing physical condition in topsoil and subsoil than the descriptive method.

So far as tropical soils are concerned, the practical importance of studying the geology probably should be emphasized more than it is in this book. The factor of ' age of site ' and that of the time during which particular pedogenic processes have operated should perhaps, on the other hand, be referred to as matters mainly of academic interest, requiring much investigation before reliable conclusions can be drawn. In the remark that in the tropical rain forest organisms bring about ' very rapid mineralization of all the plant debris ', ' humification ' would be more correct than ' mineralization ', for organic matter appears to be at least as important in tropical soils as in temperate soils, and its presence and effects should be carefully observed by the field man. That certain tropical soils ' show no visible humus whatever ' (page 100) may be questioned. That in the tropical rain forest there is ' rarely any appreciable accumulation of litter ' (page 95) should perhaps be qualified by noting that Richards, in *The Tropical Rain Forest*, mentions the occurrence of true podsols with fairly thick humus layers in various places.—H.V.

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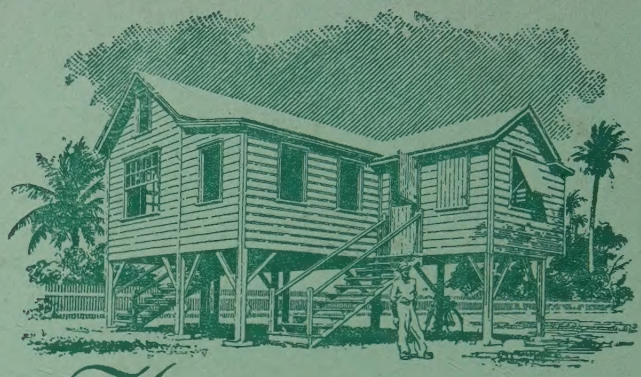

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